New Vertical Moist Thermodynamic Structure of the MJO in AIRS Observations

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Thanks

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Ed Olsen, Sung-Yung Lee, Stephanie Granger

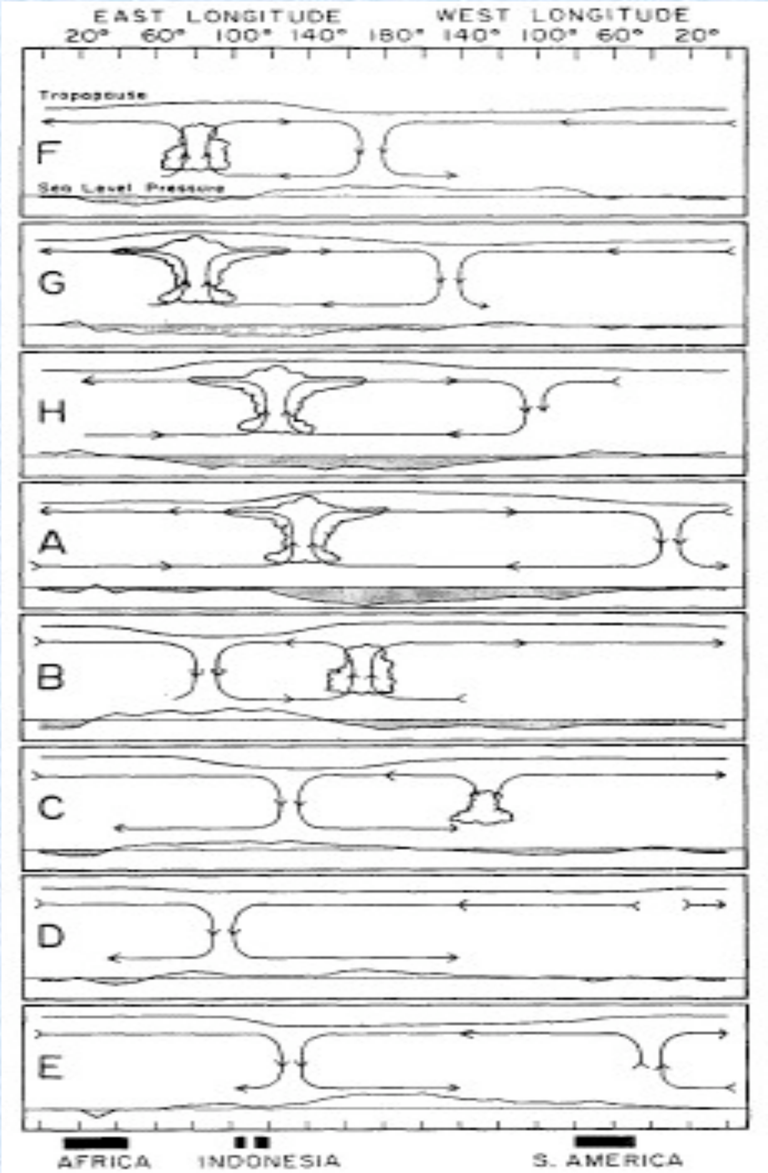
AIRS Science Team Meeting, March 7, 2006, Pasadena, CA

Outline

- MJO
- Motivation and Objective
- Data and Methodology
- Observed MJO Vertical Structure from AIRS
- Comparison between AIRS and NCEP
- Implication for MJO Theory
- Summary

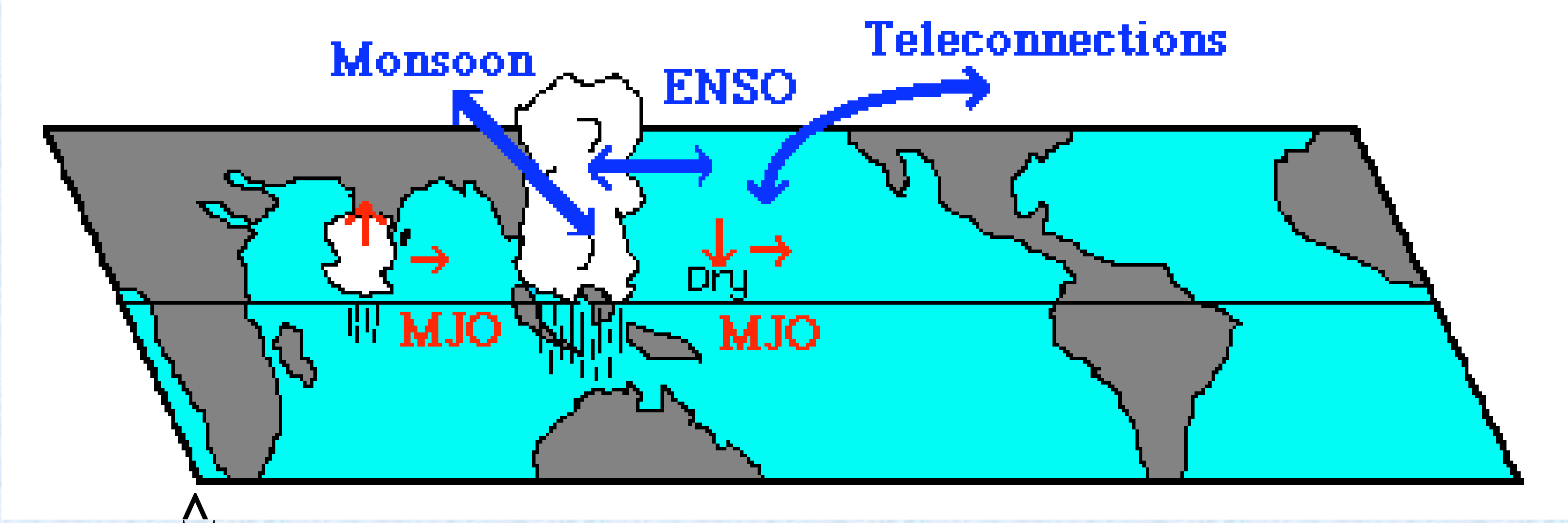
Madden-Julian Oscillation

(a.k.a. Intraseasonal, 40-50, 30-60 Day Oscillation)



- ❖ Intraseasonal Time Scale: 30-60 days
- ❖ Slow Eastward Propagation:
  ~5 m/s Phase Speed
- ❖ Strong Coupling Between Deep Convection and Large-Scale Circulation
- ❖ Planetary Zonal Scale (Wavenumber One-Two)
- ❖ Vertical Baroclinic Structure
- ❖ Equatorially Trapped
- ❖ Strong Geographic Preference: The Tropical Indian and West Pacific Oceans ("Warm Pool")
- ❖ Strong Seasonal Dependence:
  NH Winter: Strong; Eastward Propagation
  NH Summer: Weak, Northeast Propagation
- ❖ Significant Interannual Variability
- ❖ Scale Interaction with Many Other High-Frequency, Small-Scale Convective Systems

Madden & Julian, 1972; 2005; Wang 2005; Zhang 2005



<Days –Weeks – Months – Seasons -Years->

- Diurnal Cycle
- Tropical Weather
  - Low-frequency Weather Modulation
- Tropical Cyclones and Hurricanes
- Midlatitude Circulations
- Asian-Australian Monsoon
  - Onset and Break Periods
- Tropical Oceans
  - ENSO
  - Decadal Variability (Indian Ocean?)
  - Mean Ocean Climate

Courtesy of D. Waliser

Challenge

Understanding, modeling, and predicting the MJO remains an unmet challenge for tropical atmospheric scientists and oceanographers (Lau and Waliser 2005; Zhang 2005).

Vertical moist thermodynamic structure of the MJO is not well understood because of the dearth of high vertical resolution temperature and humidity data.

AIRS/AMSU Sounding System

Through multi-spectral coverage in infrared and microwave channels, the AIRS/AMSU system obtains vertical profiles of atmospheric temperature and water vapor with vertical resolution of 1-2 km, horizontal resolution of 45 km, temporal resolution of twice daily, radiosonde accuracy, global coverage, and for cloud cover up to about 70%.

Objective

To characterize the vertical moist thermodynamic structure and spatial-temporal evolution of the MJO by exploiting the high-resolution AIRS/AMSU soundings.

To illustrate areas where confidence can be ascribed to the reanalyses as well as where caution might be warranted by comparing results from AIRS and NCEP.

To validate MJO theories and improve our theoretical understanding of the MJO.

Data

- **AIRS L3 v4.0.8.0 Water Vapor and Temperature Soundings**

  Temp: 24 WMO Standard Levels from 1000 to 1 mb
  WV: 12 Lowest WMO Standard Layers from 1000 to 100 mb
  1° x 1°, Daily, From 09/01/2002 to 01/26/2005

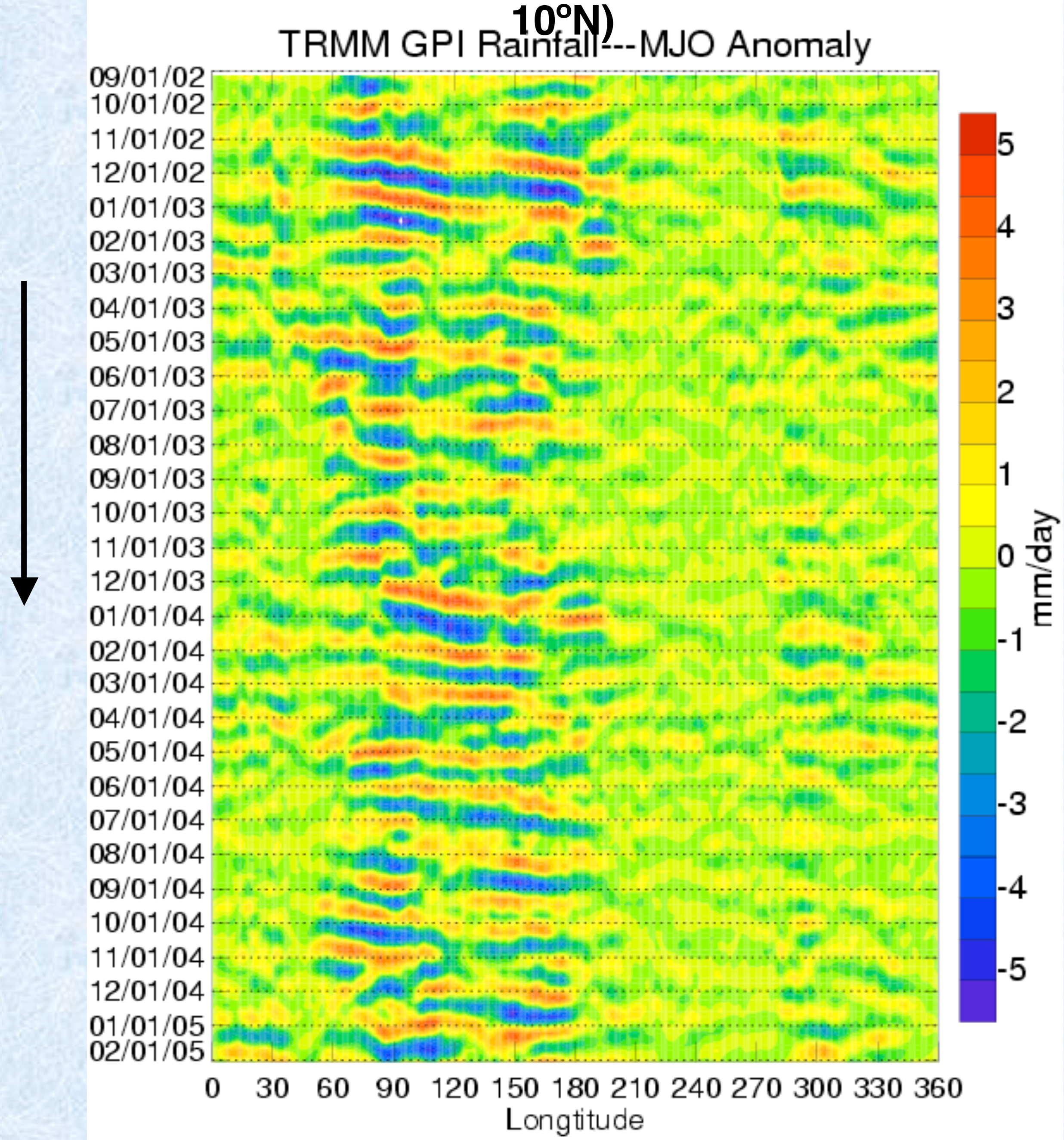
- **NCEP Water Vapor and Temperature Profiles**

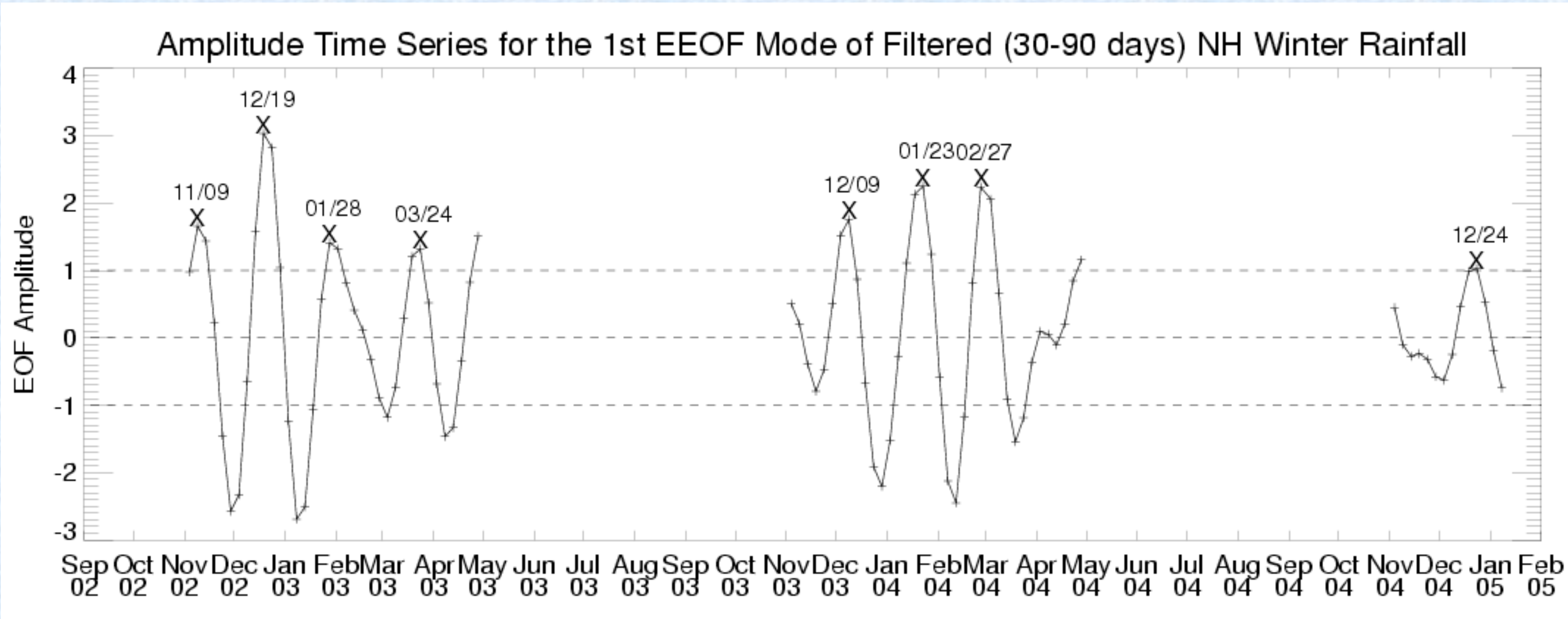
  Temp: 17 lvls from 1000 to 10 mb; WV: 8 lvls from 1000 to 300mb
  2.5° x 2.5°, Daily, From 09/01/2002 to 01/26/2005

- **TRMM GOES Precipitation Index (GPI) Rainfall**

  1° x 1°, Daily, From 01/01/1998 to 02/04/2005

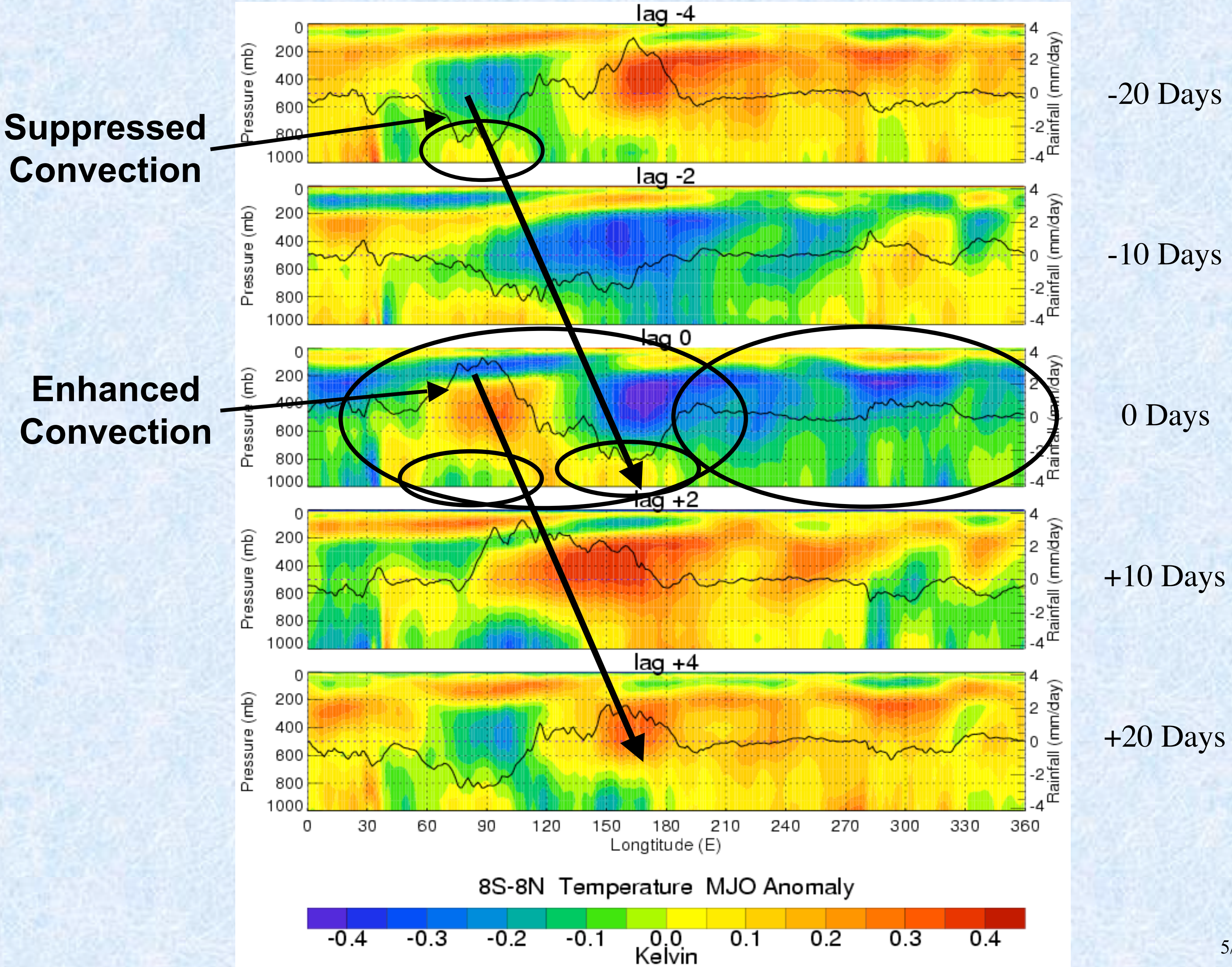
Hovmöller diagram of TRMM rainfall MJO anomaly (averaged from 10ºS-10ºN)





Amplitude pentad time series for the first EEOF mode of TRMM rainfall anomaly from NH wintertime (November–April) and the region 30ºN–30ºS and 30ºE–150ºW.

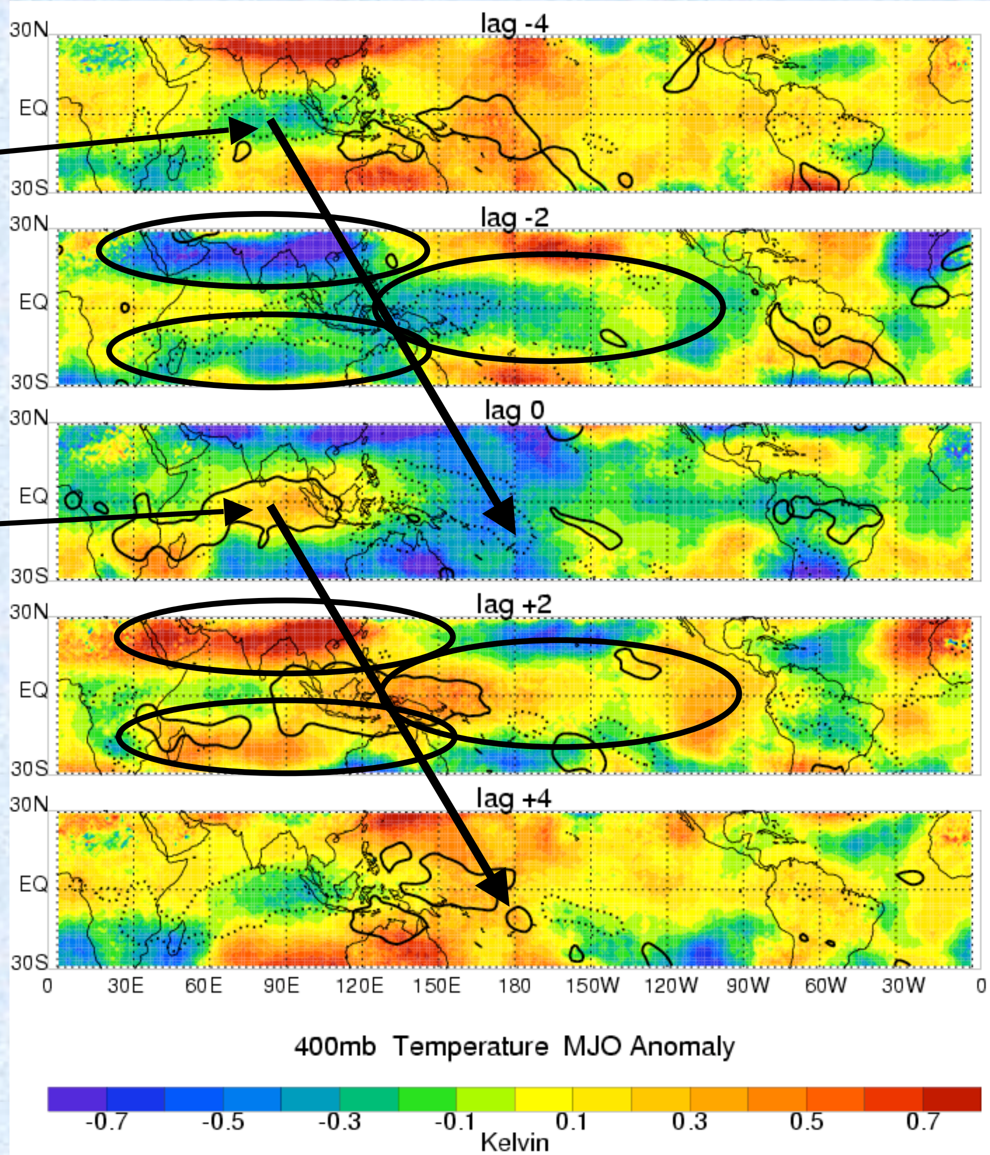
Pressure-Longitude Diagrams of Temperature Anomaly Along Equator for the MJO;
TRMM Rainfall Anomaly Shown as Line Plot (right axis); Panels Separated by 10 Days



Longitude-Latitude Maps of MJO Temperature Anomaly in the Free Troposphere (400 hPa);
TRMM Rainfall Anomaly Shown as Line Plot (solid, +1 mm/day; dashed, -1 mm/day);
Panels Separated by 10 Days

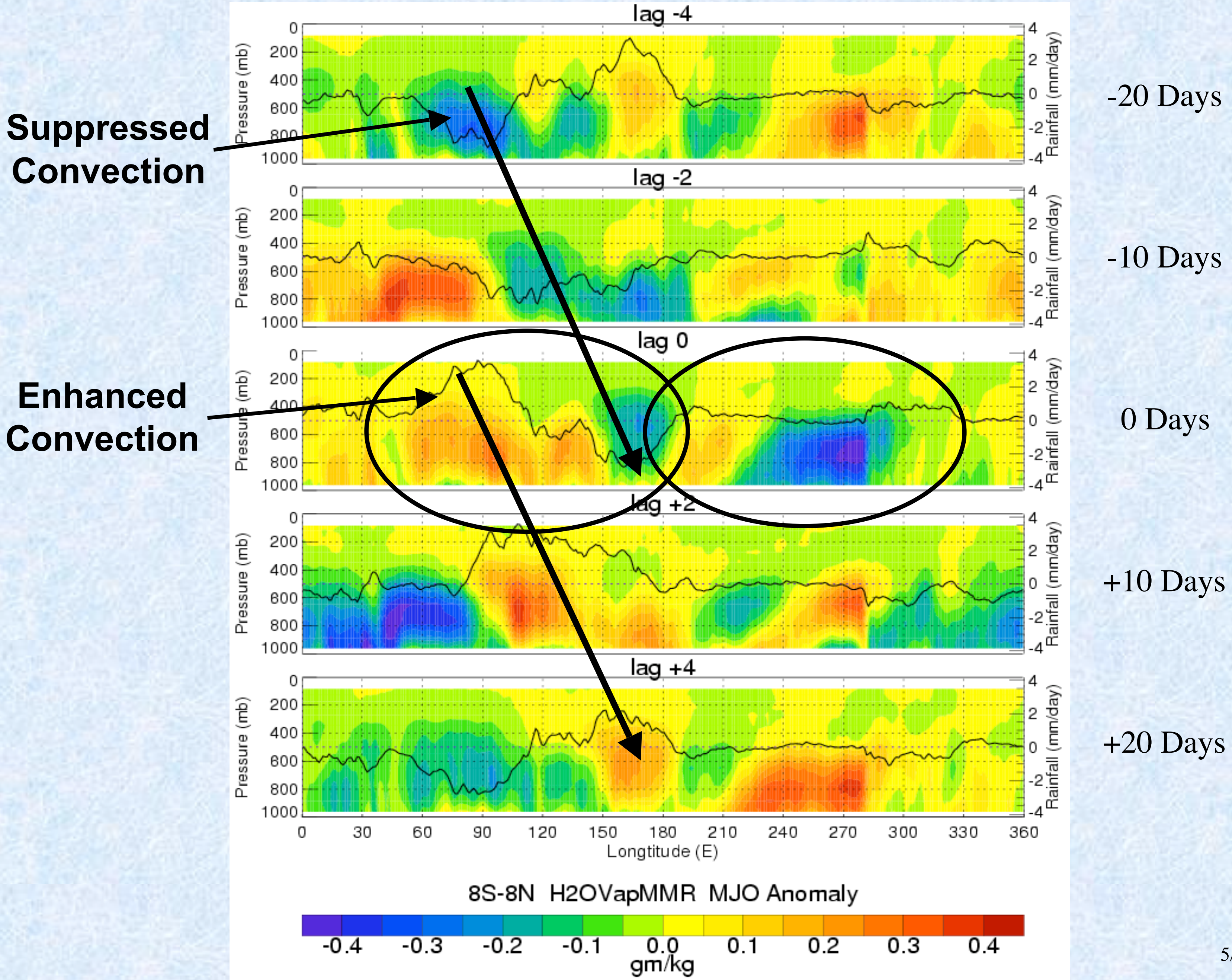
Suppressed Convection

Enhanced Convection



A warm (cold) anomaly (~0.4 K) is collocated with enhanced (suppressed) convection.

Pressure-Longitude Diagrams of Moisture Anomaly Along Equator for the MJO;
TRMM Rainfall Anomaly Shown as Line Plot (right axis); Panels Separated by 10 Days



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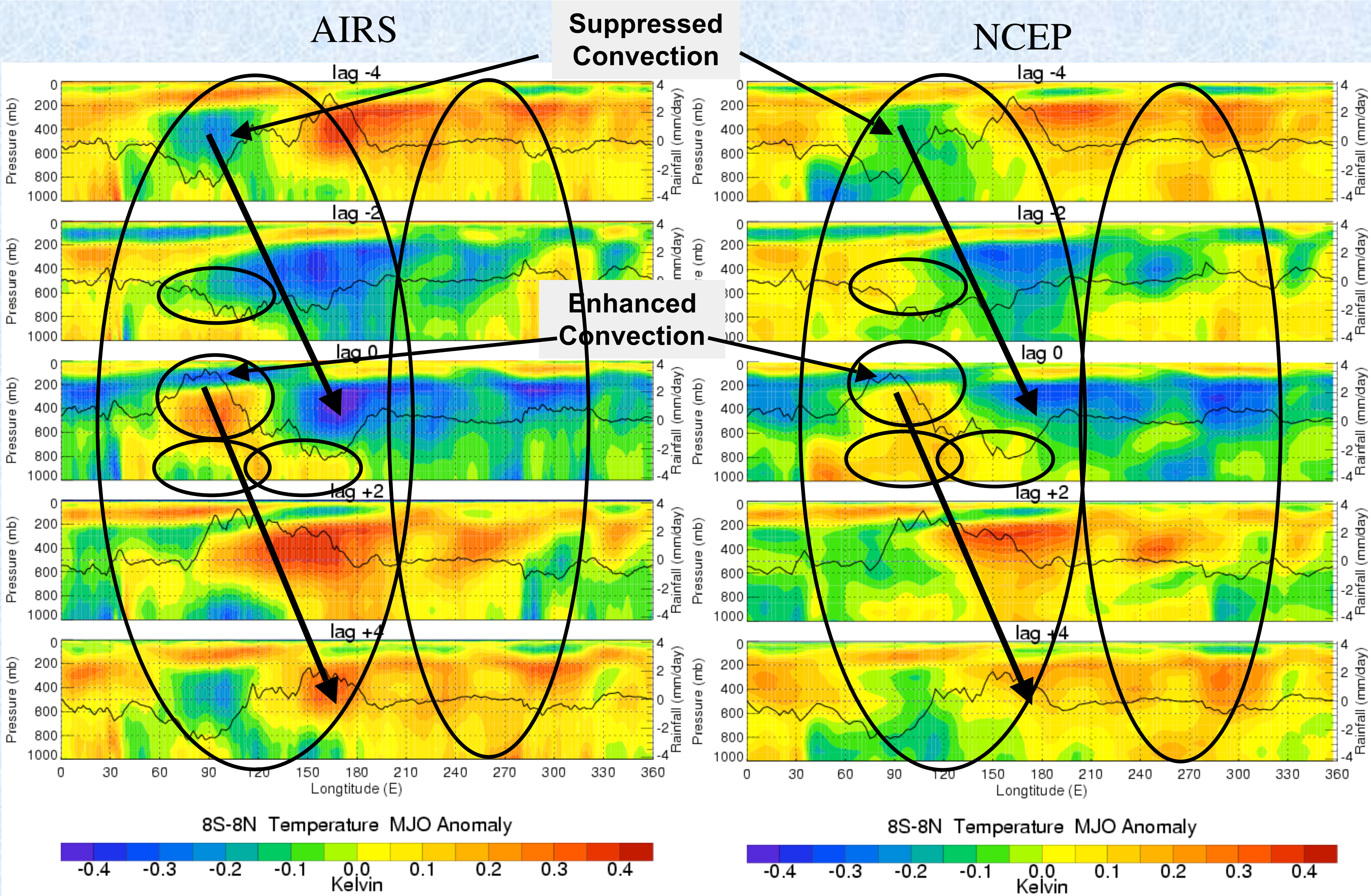
What's New from AIRS?

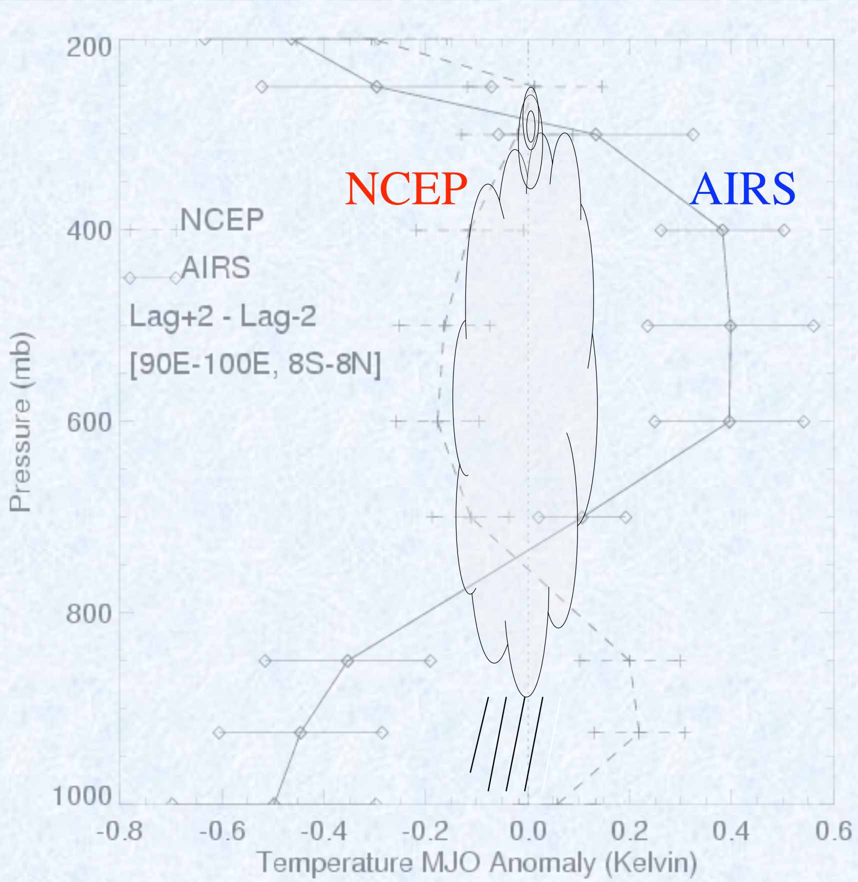
Can We Get the Similar MJO Vertical Structure from NCEP?



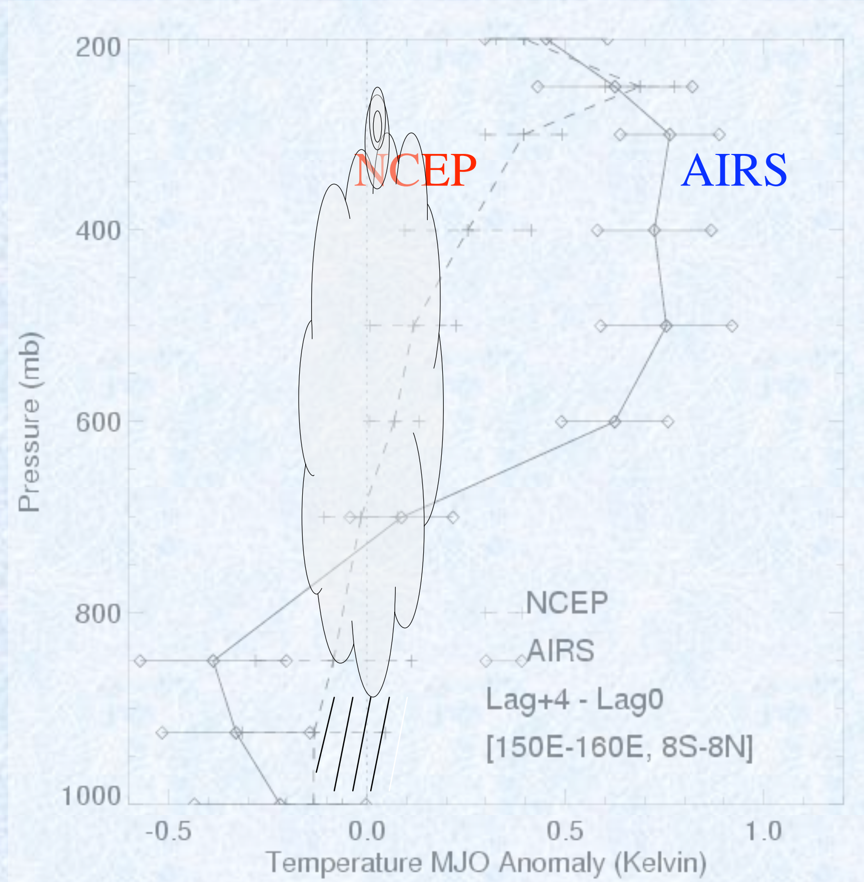
- In AIRS, a boundary-layer temperature anomaly precedes the tropospheric temperature anomaly in a somewhat consistent way for both the Indian and western Pacific Ocean. This doesn’t appear to be the case for the NCEP results.

Vertical Profiles of MJO Temperature Anomaly In the Indian & W.Pacific Ocean

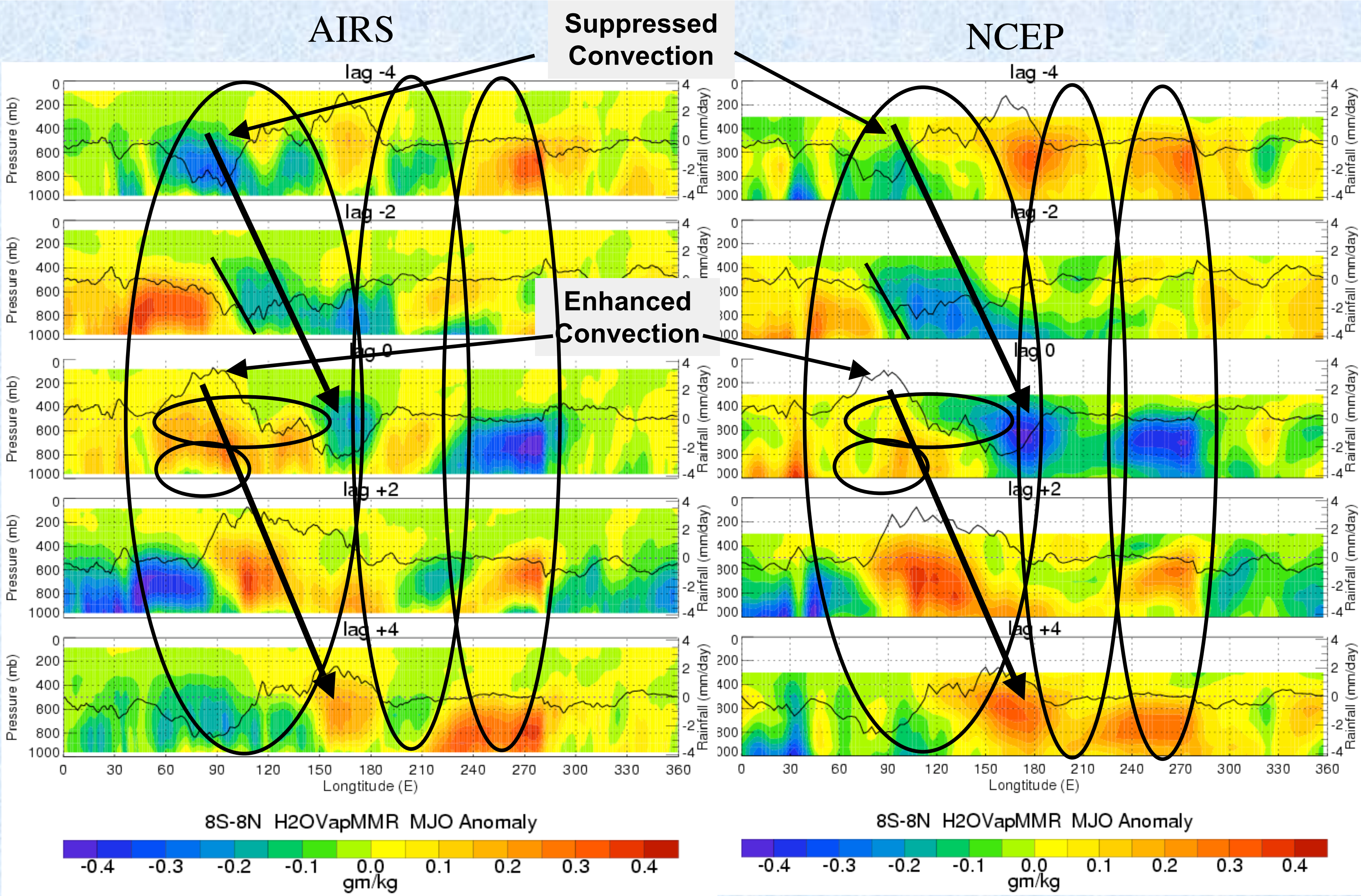
Indian Ocean



Western Pacific Ocean

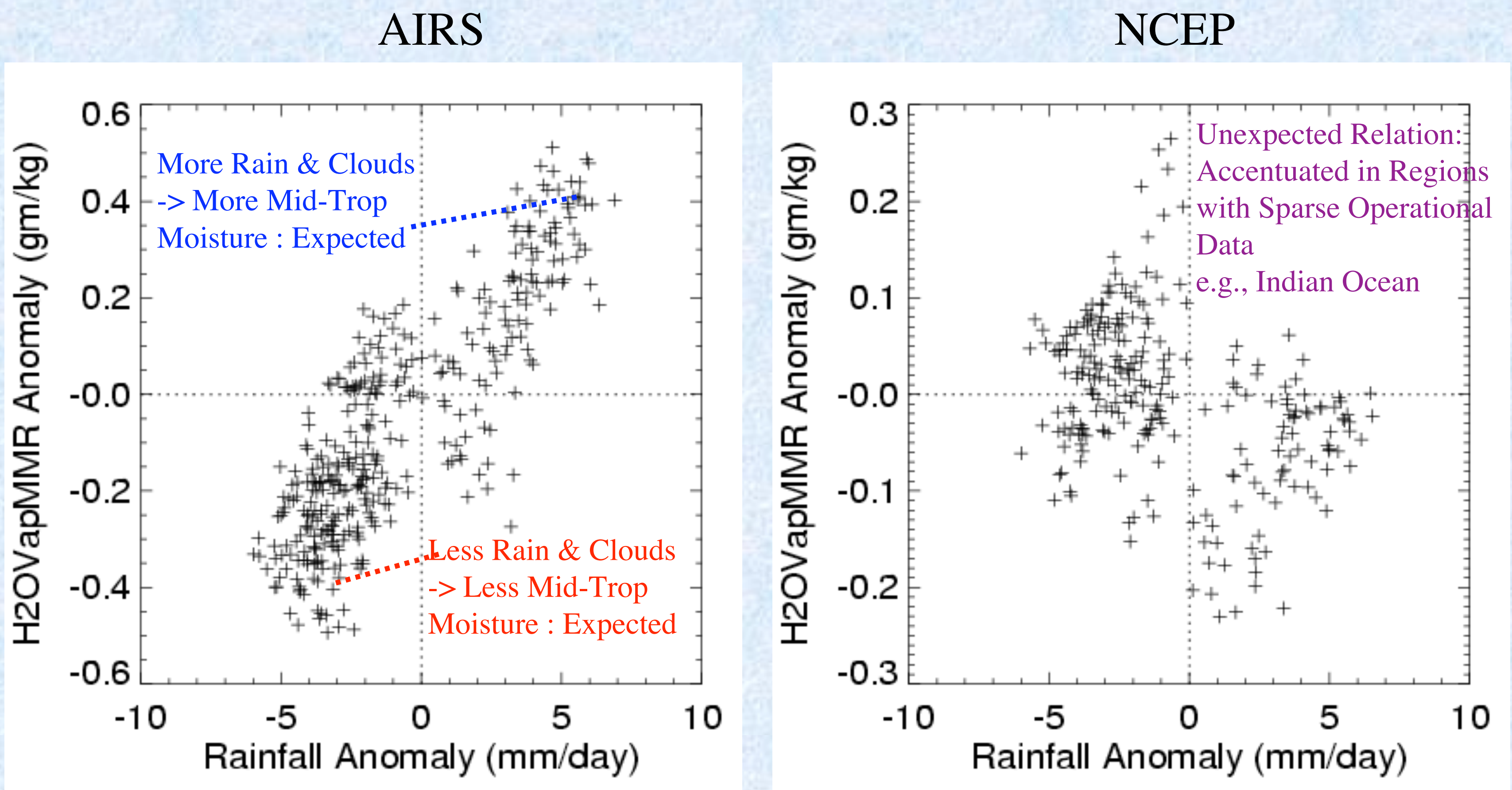


- The plot on the left shows the profiles over the Indian Ocean for Lag +2 pentads (*disturbed*) minus Lag -2 pentads (*suppressed*). The plot on the right shows the profiles over the western Pacific Ocean for Lag +4 pentads (*disturbed*) - Lag 0 pentads (*suppressed*).
- The AIRS data exhibit stronger lower-tropospheric (free tropospheric) cooling (warming) compared to the NCEP for the implied conditions - i.e. positive precipitation anomalies.

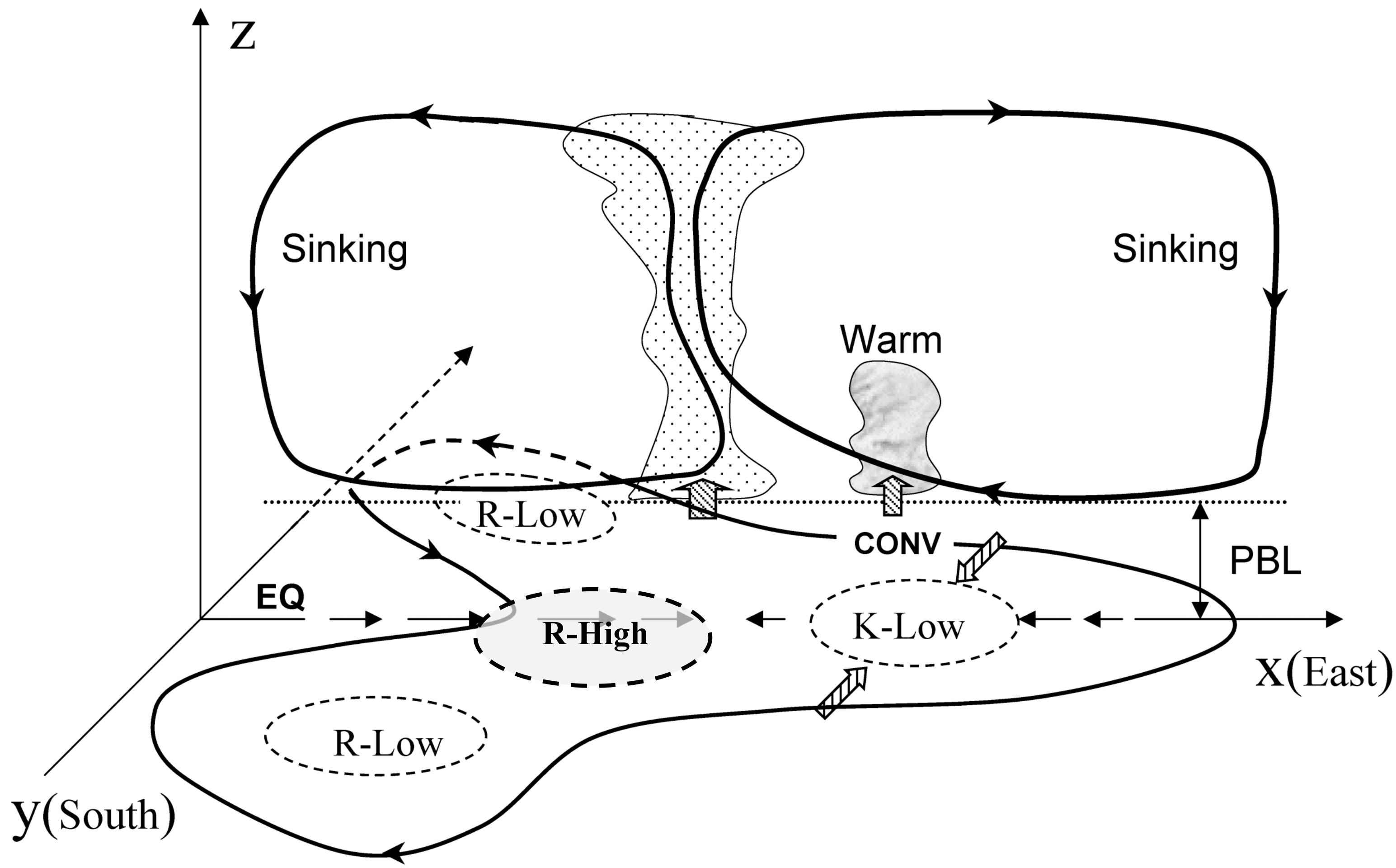


- In this region of sparse in-situ data, there is considerable disagreement between AIRS and NCEP.

Relation Between TRMM Rainfall and Mid-Troposphere Water Vapor Anomalies In the Equatorial Indian Ocean (8°S-8°N, 70°E-100°E) for the MJO



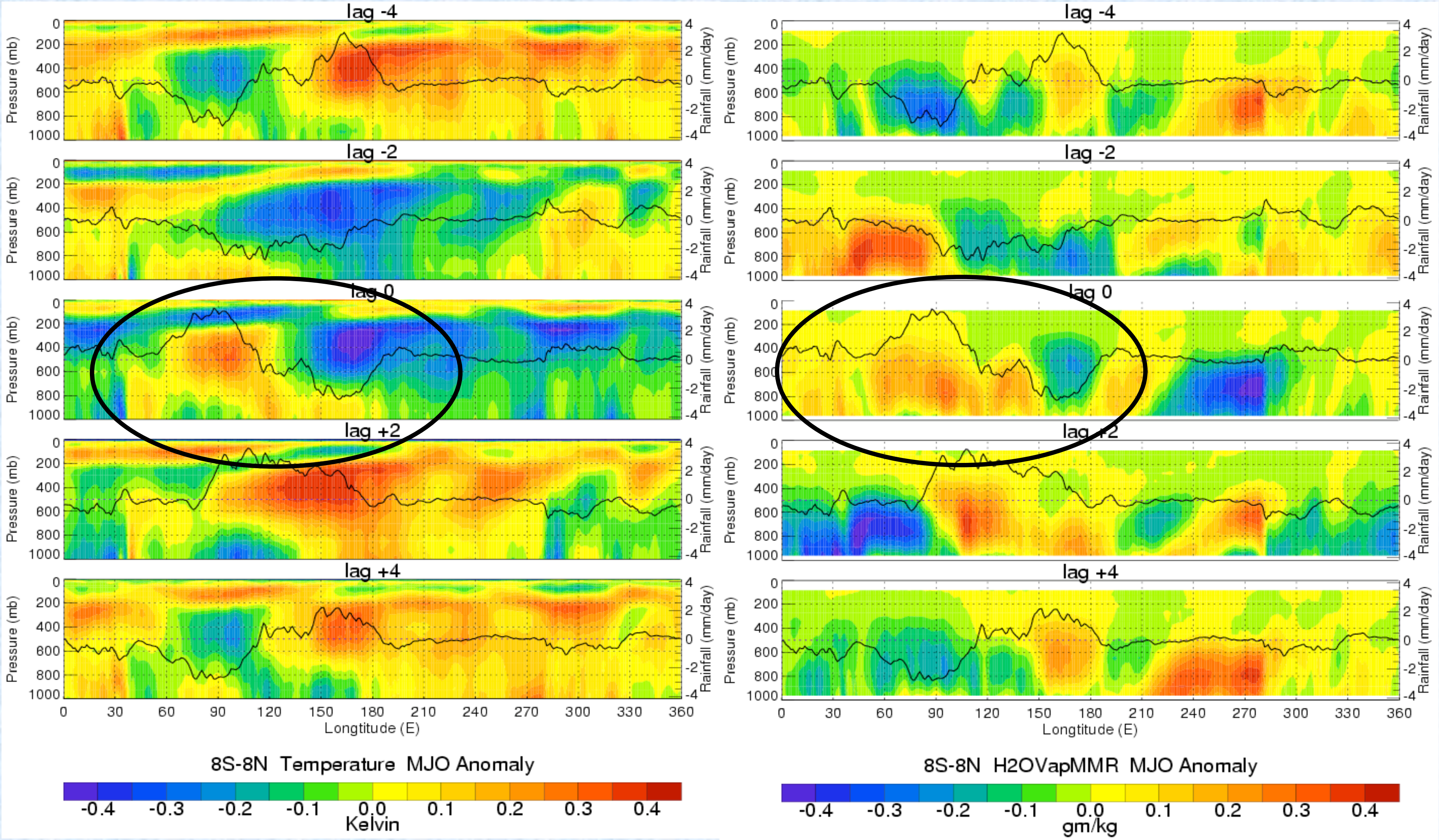
- The data points plotted are based on a combination of the strongly disturbed (Lag 0 pentads) and strongly suppressed (Lag -4 & +4 pentads) phases of the MJO.
- The left plot is based on AIRS mid-tropospheric (547 hPa) water vapor and TRMM rainfall anomalies.
- The right plot is based on NCEP mid-tropospheric (500 hPa) water vapor and TRMM rainfall anomalies.
- The AIRS data exhibits a more realistic relationship to the TRMM rainfall anomalies - at least for this region where in-situ data is sparse.



Schematic structure of the frictional convergence feedback or frictional wave-CISK model for the MJO (Wang 1998; 2005).

Courtesy of B. Wang

Pressure-Longitude Diagrams of MJO Temperature/Water Vapor Anomaly Along Equator



Summary - I

- **The AIRS data indicate that, in the Indian Ocean and western Pacific, the temperature anomaly exhibits a trimodal vertical structure: a warm (cold) anomaly in the free troposphere [800-250 hPa] and a cold (warm) anomaly near the tropopause [above 250 hPa] and in the lower troposphere [below 800 hPa] associated with enhanced (suppressed) convection.**

- **The AIRS moisture anomaly also shows markedly different vertical structures as a function of longitude and the strength of convection anomaly.**

- **Most significantly, the AIRS data demonstrate that, over the Indian Ocean and western Pacific, the enhanced (suppressed) convection is generally preceded in both time and space by a low-level warm and moist (cold and dry) anomaly and followed by a low-level cold and dry (warm and moist) anomaly.**

Summary - II

- The MJO vertical moist thermodynamic structure from the AIRS data is in general agreement, particularly in the free troposphere, with previous studies based on global reanalysis and limited radiosonde data.

- However, major differences in the lower-troposphere moisture and temperature structure between the AIRS observations and the NCEP reanalysis are found over the Indian and Pacific Oceans, where there are very few conventional data to constrain the reanalysis.

- Overall, the AIRS results are quite consistent with those predicted by the frictional Kelvin-Rossby wave-CISK theory for the MJO.

For More Information, please contact me at

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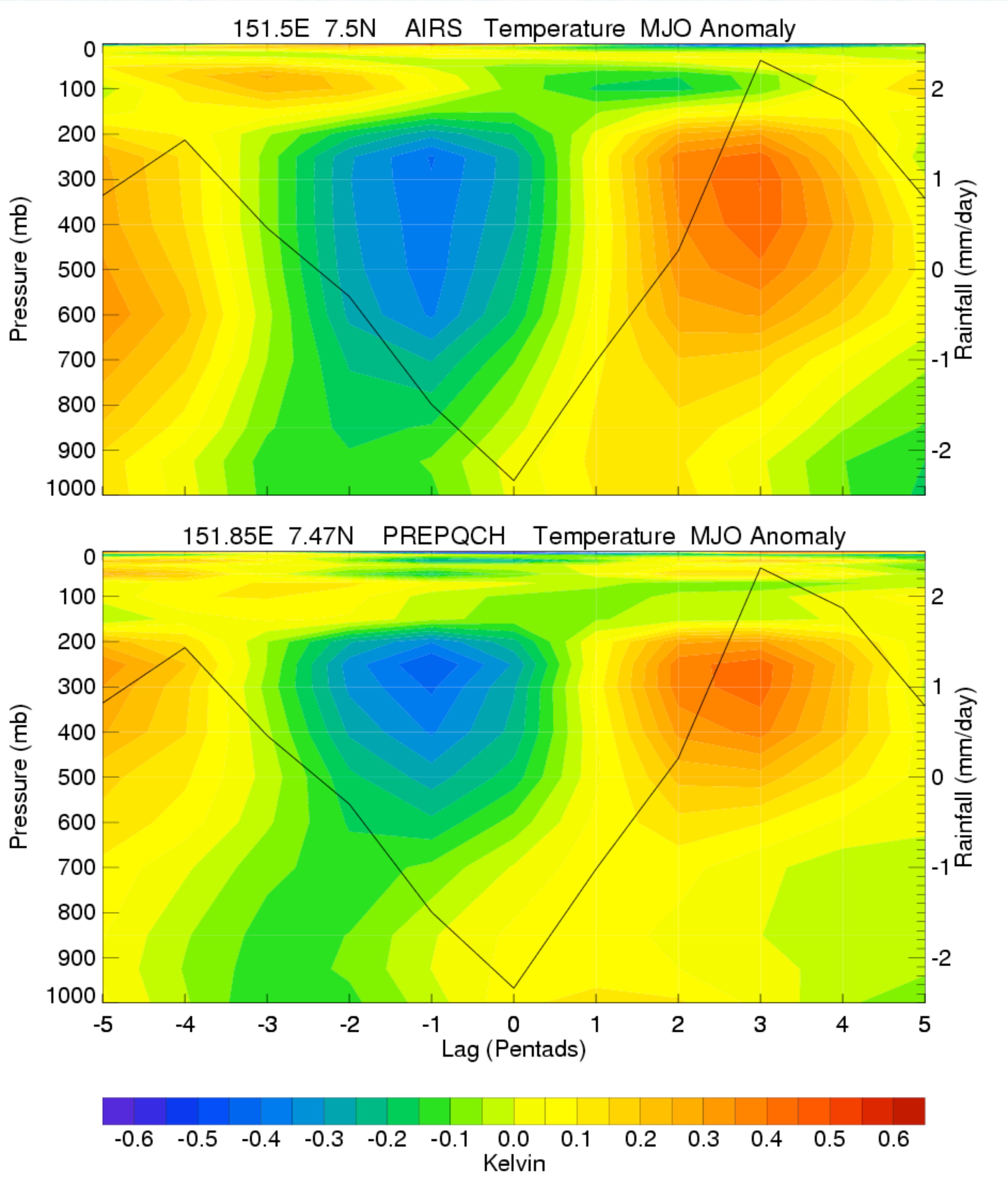
Tian, B., D. E. Waliser, E. J. Fetzer, B. H. Lambrigtsen, Y. L. Yung, and B. Wang, 2006: Vertical Moist Thermodynamic Structure and Spatial-temporal Evolution of the MJO in AIRS Observations. *J. Atmos. Sci.*

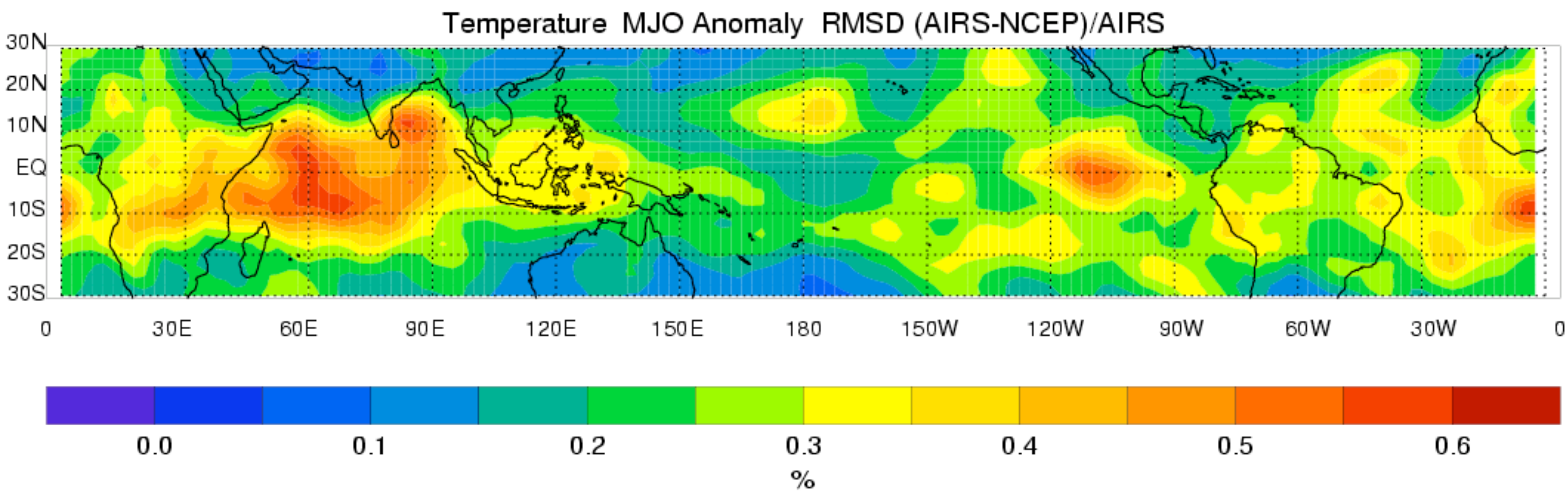
THE END

THANK YOU

Backup Slides

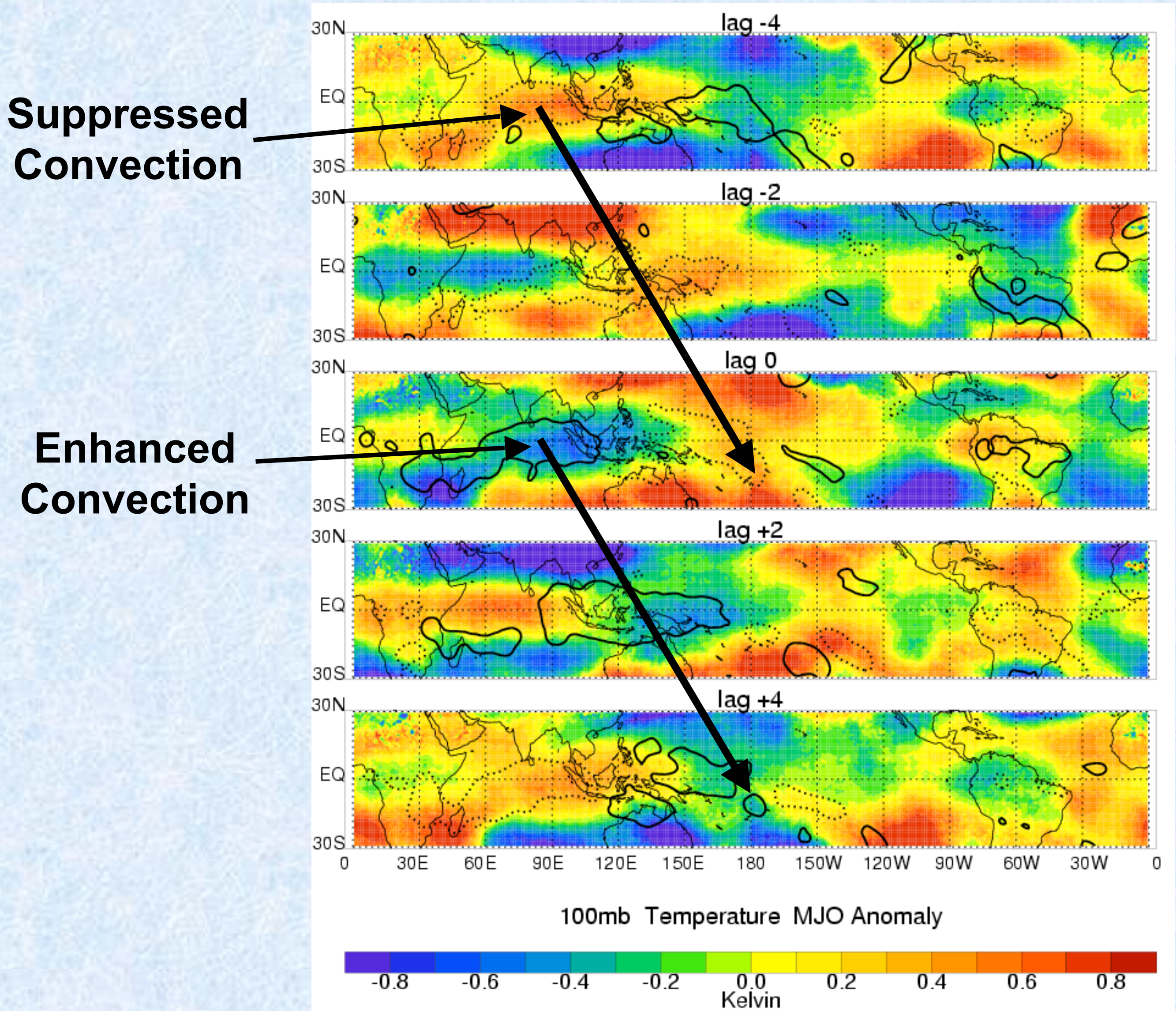
MJO vertical temperature structure using AIRS (top) and radiosonde (bottom) at Truk (7.47ºN, 151.85ºE). The superimposed solid black line denotes the collocated TRMM rainfall anomaly (mm/day).





Temperature anomaly root mean square difference (RMSD) between AIRS and NCEP.

Longitude-Latitude Maps of MJO Temperature Anomaly in the Tropopause Region (100 hPa);
TRMM Rainfall Anomaly Shown as Line Plot (solid, +1 mm/day; dashed, -1 mm/day);
Panels Separated by 10 Days

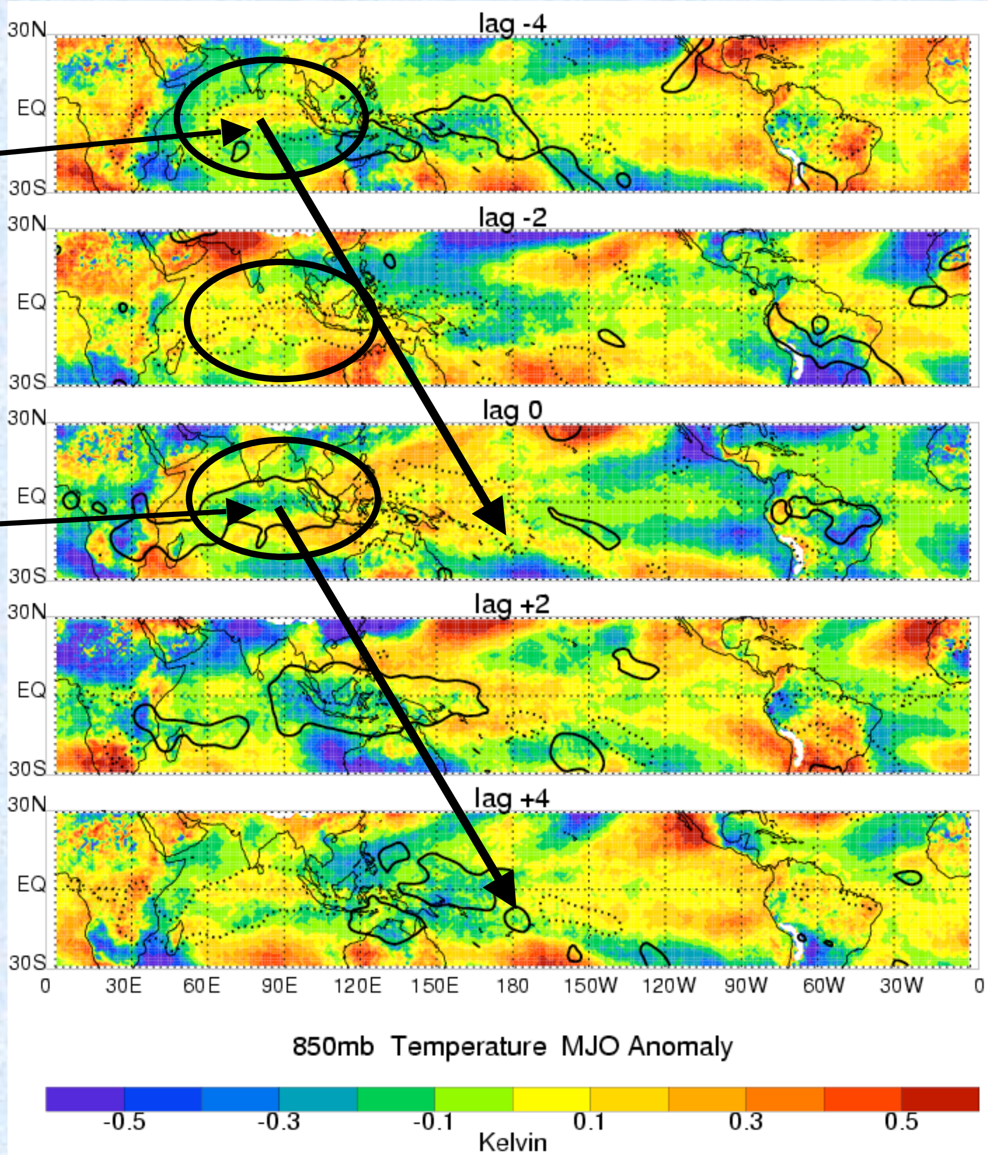


A cold (warm) anomaly (~0.2 K) is collocated with enhanced (suppressed) convection.

Longitude-Latitude Maps of MJO Temperature Anomaly in the Lower Troposphere (850 hPa);
TRMM Rainfall Anomaly Shown as Line Plot (solid, +1 mm/day; dashed, -1 mm/day);
Panels Separated by 10 Days

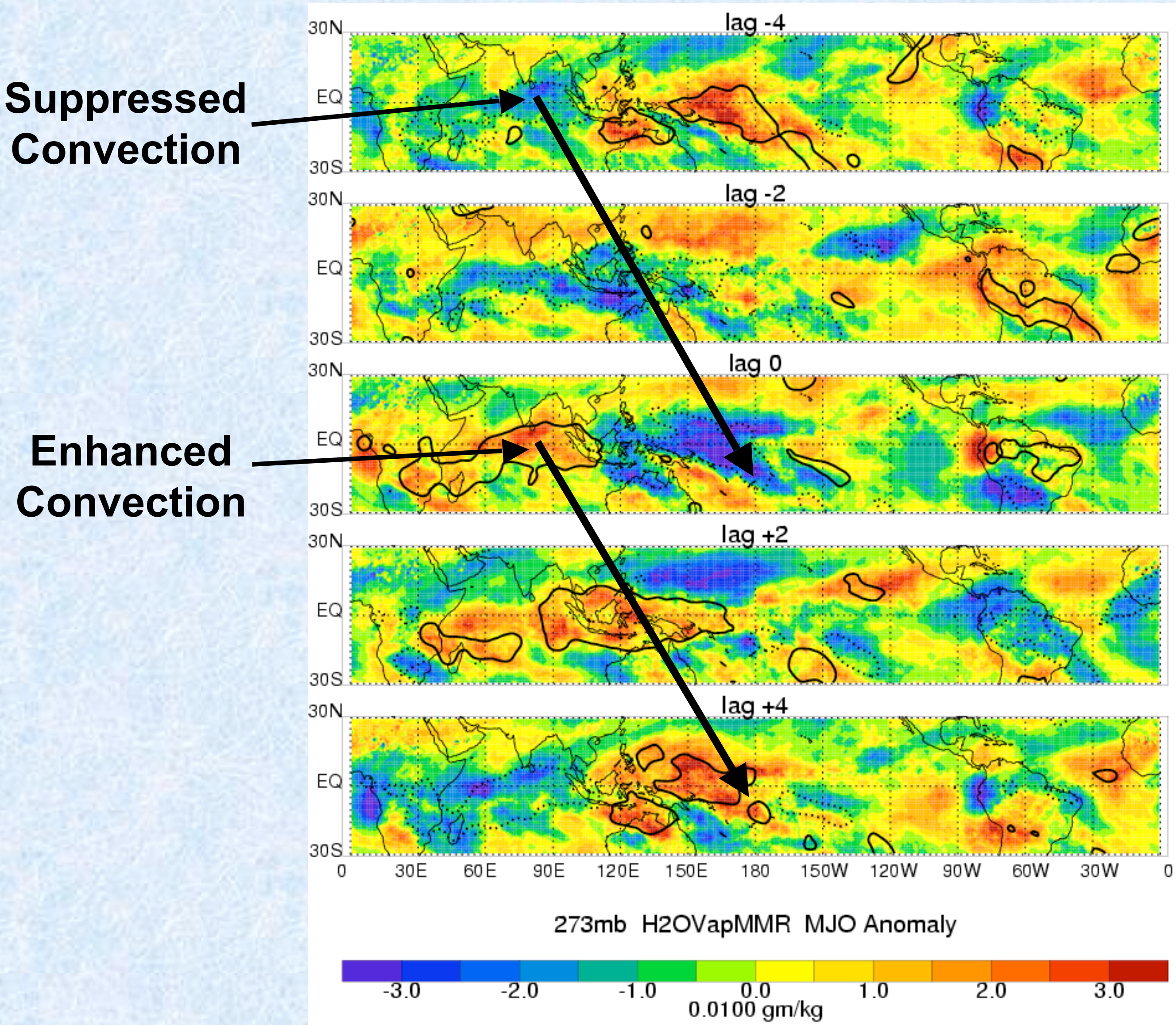
Suppressed Convection

Enhanced Convection



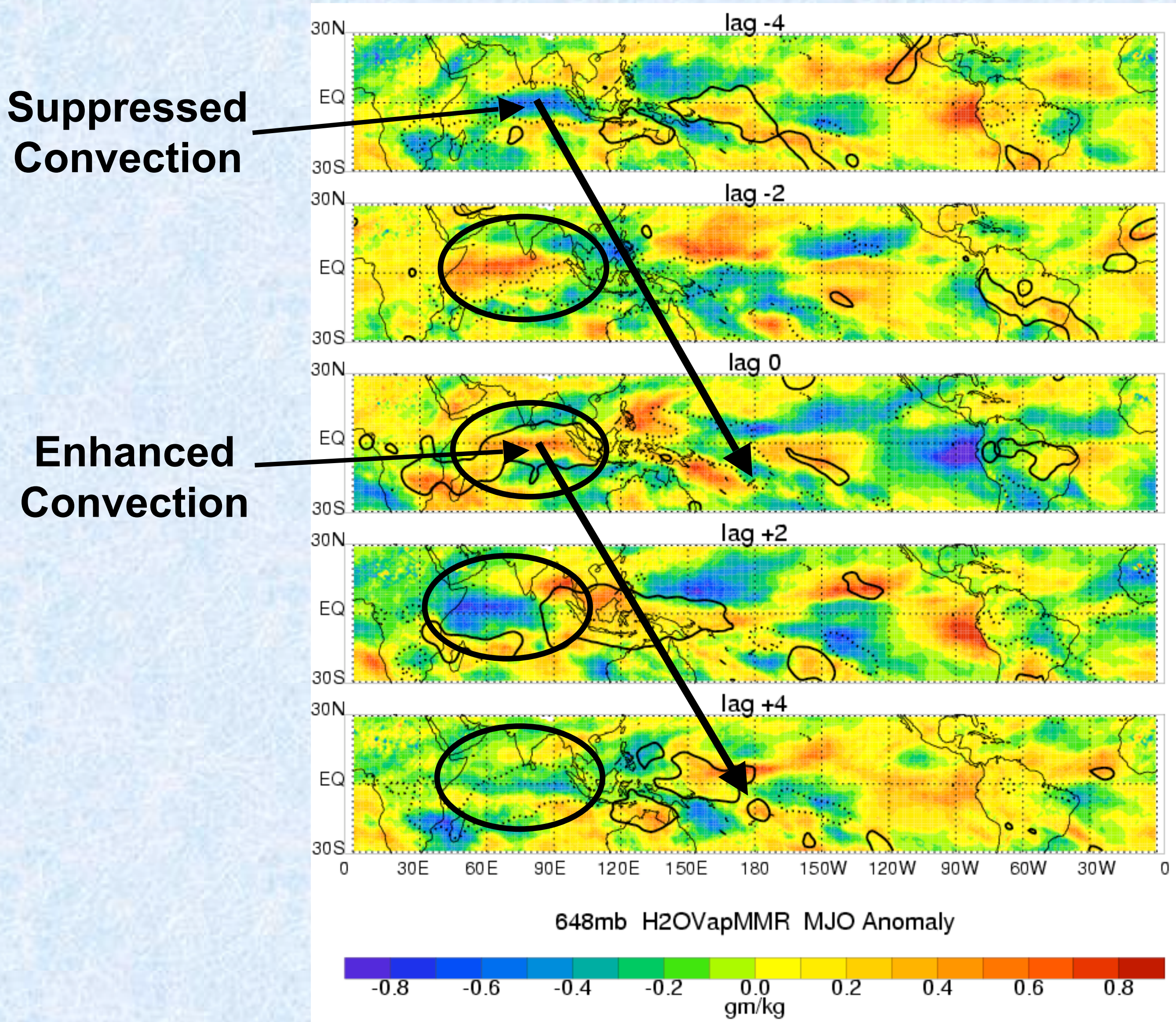
A cold (warm) anomaly (~0.2 K) is collocated with enhanced (suppressed) convection.

Longitude-Latitude Maps of MJO Moisture Anomaly in the Upper Troposphere (273 hPa);
TRMM Rainfall Anomaly Shown as Line Plot (solid, +1 mm/day; dashed, -1 mm/day);
Panels Separated by 10 Days



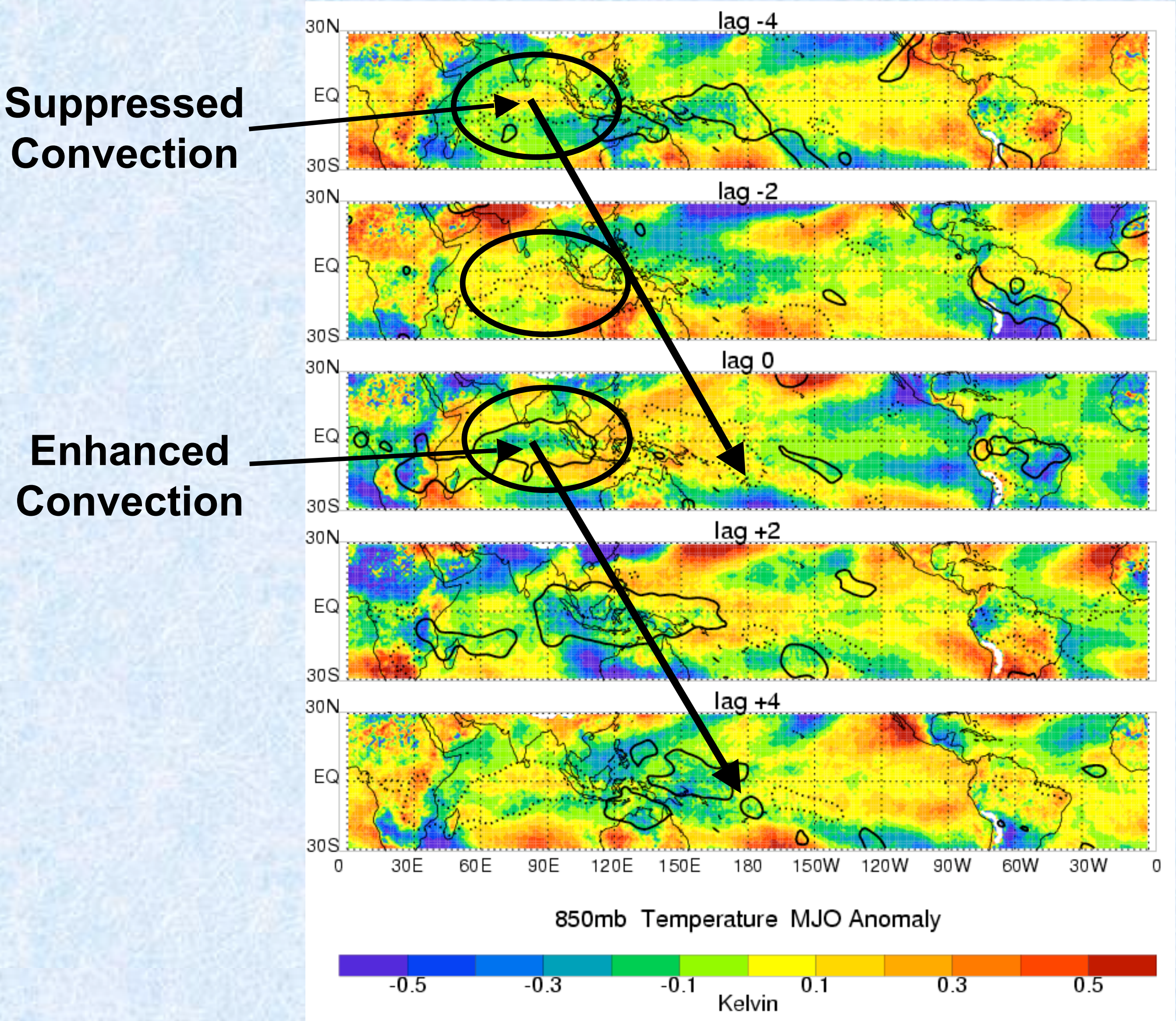
A moist (dry) anomaly (0.2 gm/kg) is collocated with enhanced (suppressed) convection.

Longitude-Latitude Maps of MJO Moisture Anomaly in the Lower Troposphere (648 hPa);
TRMM Rainfall Anomaly Shown as Line Plot (solid, +1 mm/day; dashed, -1 mm/day);
Panels Separated by 10 Days



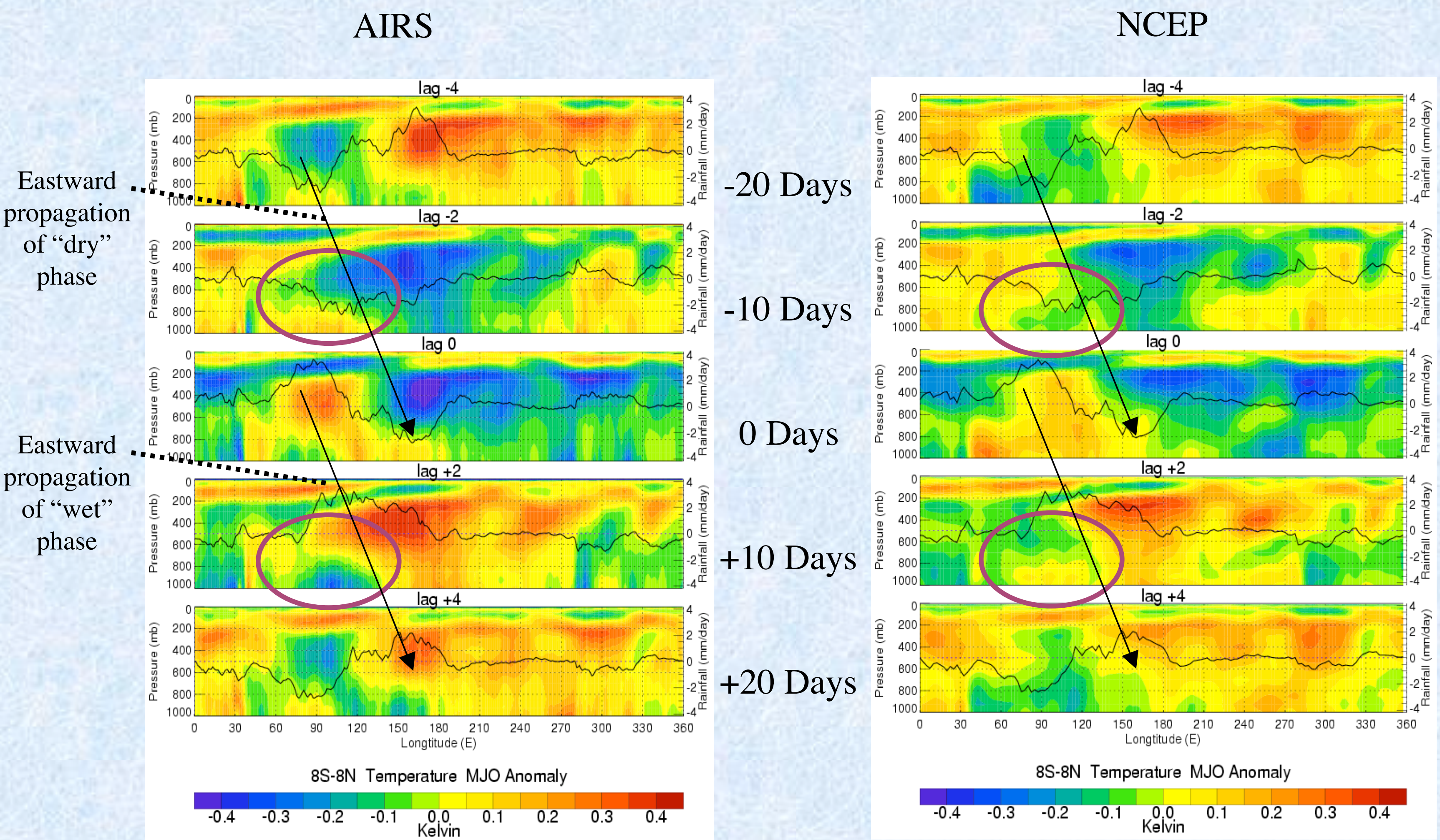
A moist (dry) anomaly (0.2 gm/kg) is collocated with enhanced (suppressed) convection.

Longitude-Latitude Maps of MJO Moisture Anomaly in the Surface Layer (961 hPa);
TRMM Rainfall Anomaly Shown as Line Plot (solid, +1 mm/day; dashed, -1 mm/day);
Panels Separated by 10 Days



A dry (moist) anomaly (0.2 gm/kg) is collocated with enhanced (suppressed) convection.

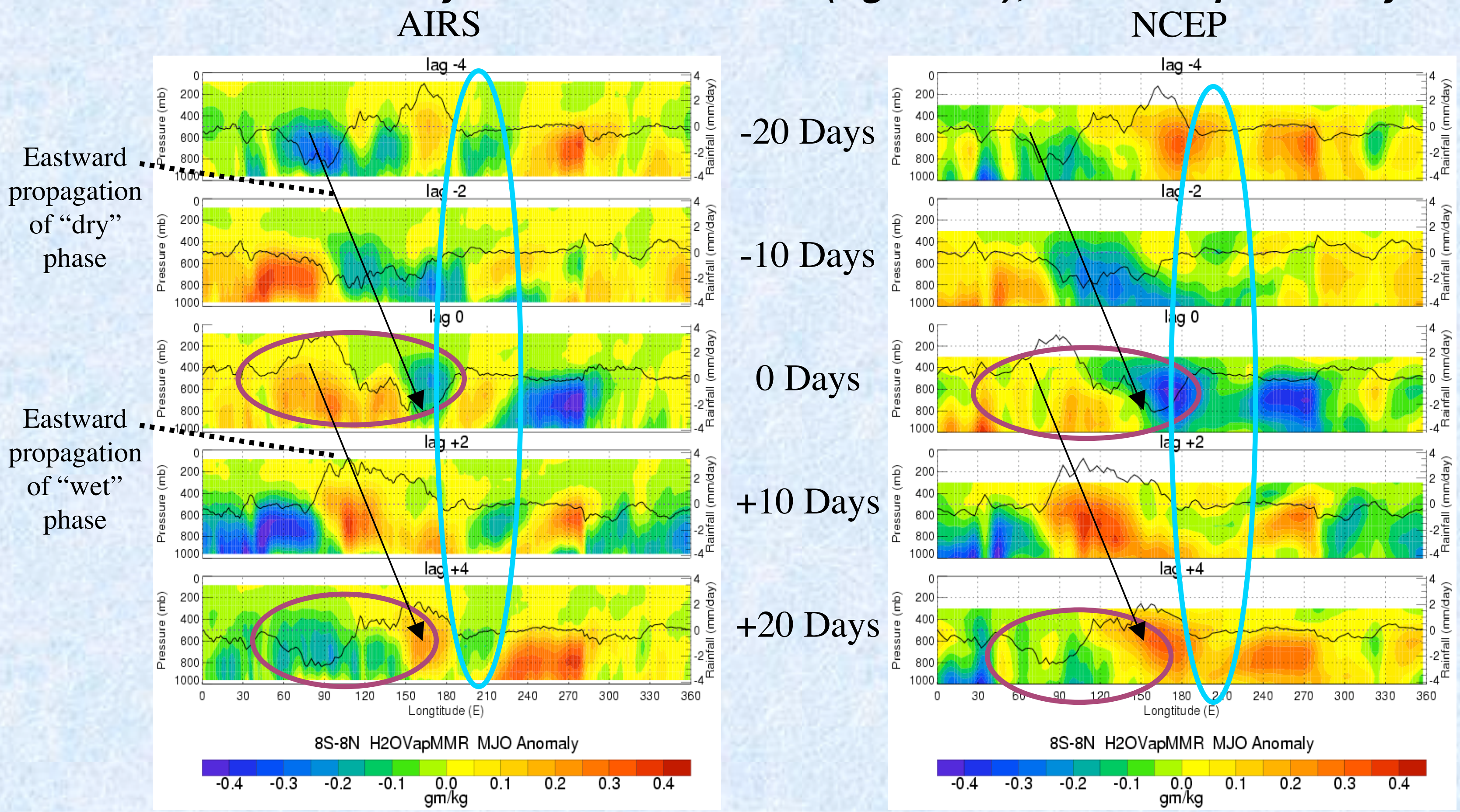
Pressure-Longitude Diagrams of Temperature Anomaly Along Equator for the MJO



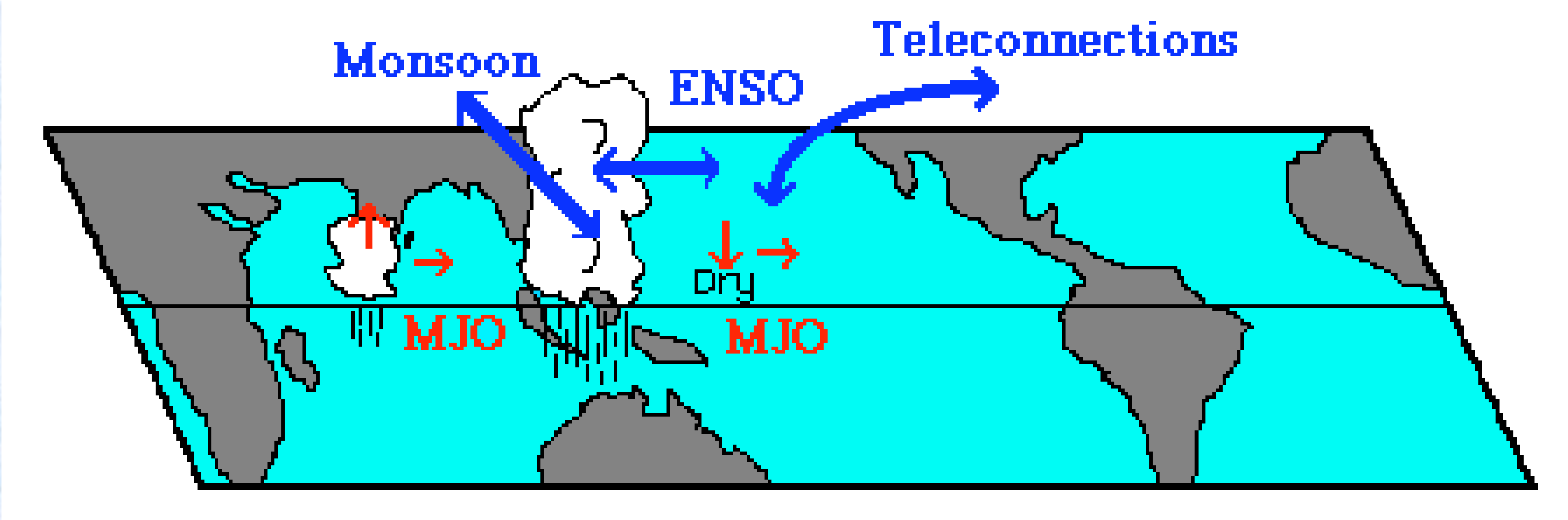
- In AIRS, a boundary-layer temperature anomaly precedes the tropospheric temperature anomaly in a somewhat consistent way for both the Indian and western Pacific Ocean. This doesn't appear to be the case for the NCEP results.
- The ovals - over the Indian Ocean - highlight important differences between AIRS and NCEP vertical temperature structure. <u>This difference is shown more concisely in the next figure.</u>

Pressure-Longitude Diagrams of Moisture Anomaly Along Equator for the MJO

TRMM Rainfall Anomaly Shown as Line Plot (right axis); Panels Separated by 10 Days



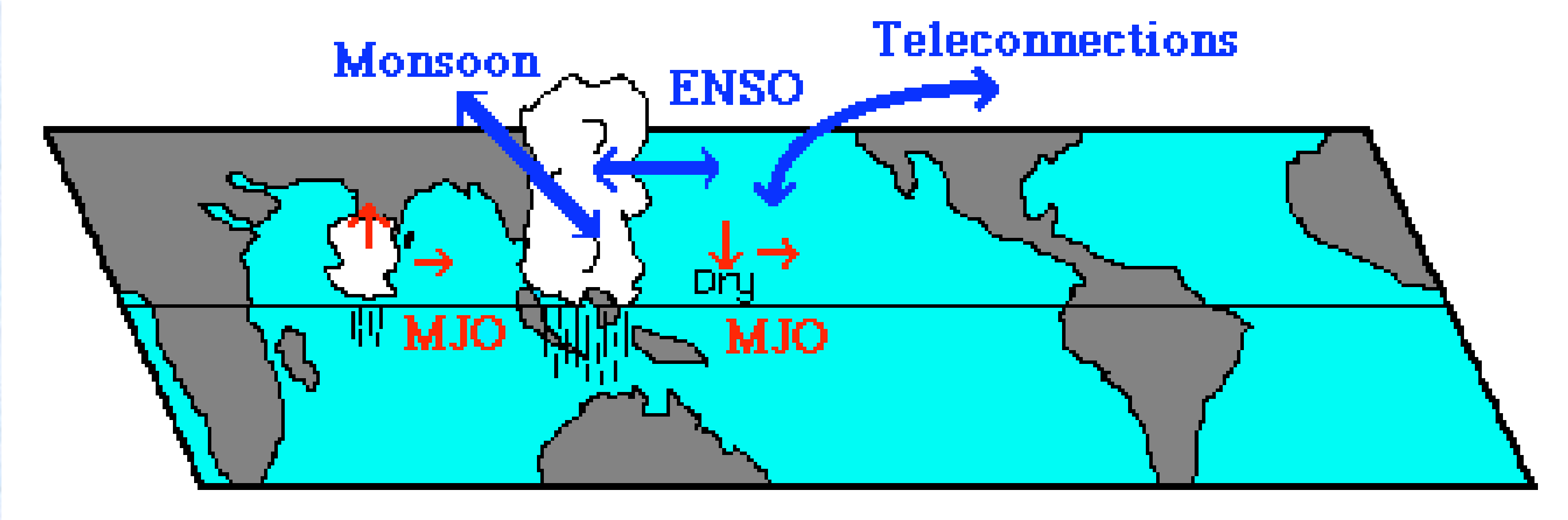
- The ovals highlight important differences between AIRS and NCEP/NCAR vertical water vapor structure.
- Dark Ovals: Examination of the mid-tropospheric water vapor anomalies and the TRMM rainfall anomalies illustrates a rather close correspondence with AIRS, less so with NCEP. <u>This difference is shown more concisely in the next slide - highlighting specifically the Indian Ocean.</u>
- Light Ovals: In this region of sparse in-situ data, there is considerable disagreement between AIRS and NCEP/NCAR.



<Days –Weeks – Months – Seasons -Years->

- Diurnal Cycle

Courtesy of D. Waliser

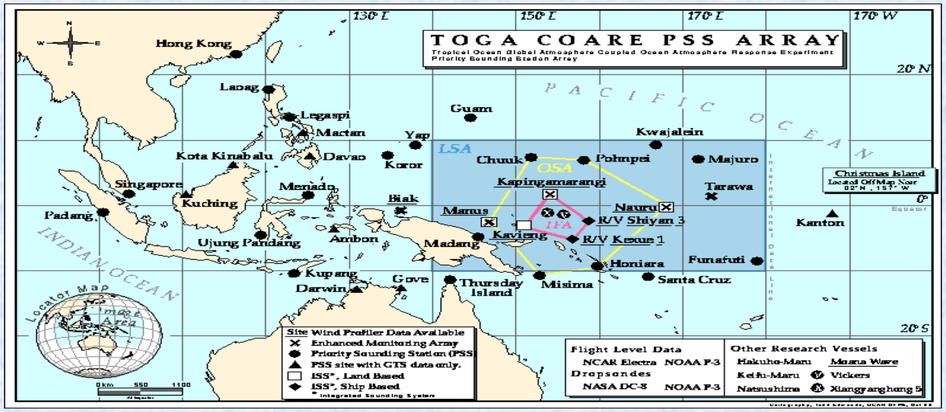


<Days –Weeks – Months – Seasons - Years->

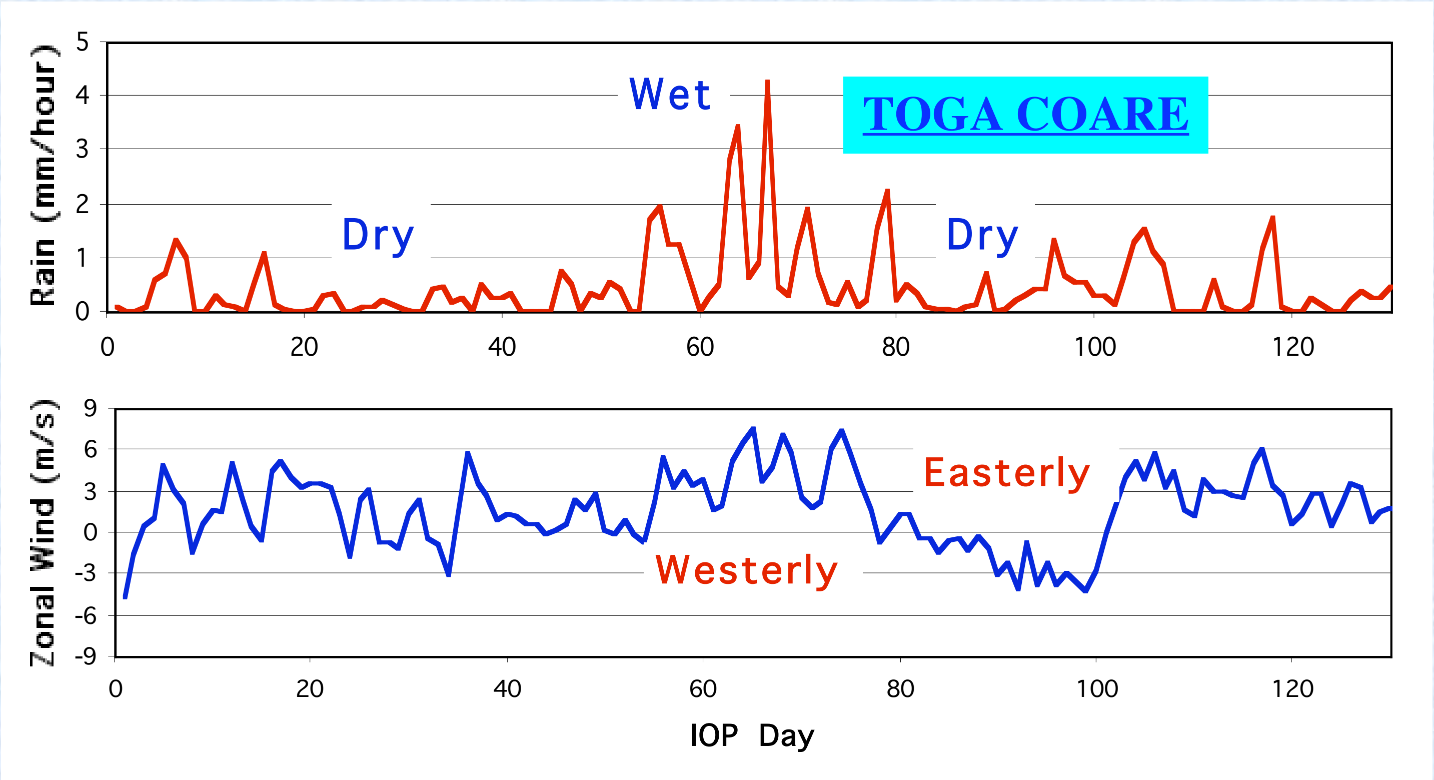
- Diurnal Cycle
- Tropical Weather

  Low-frequency Weather Modulation

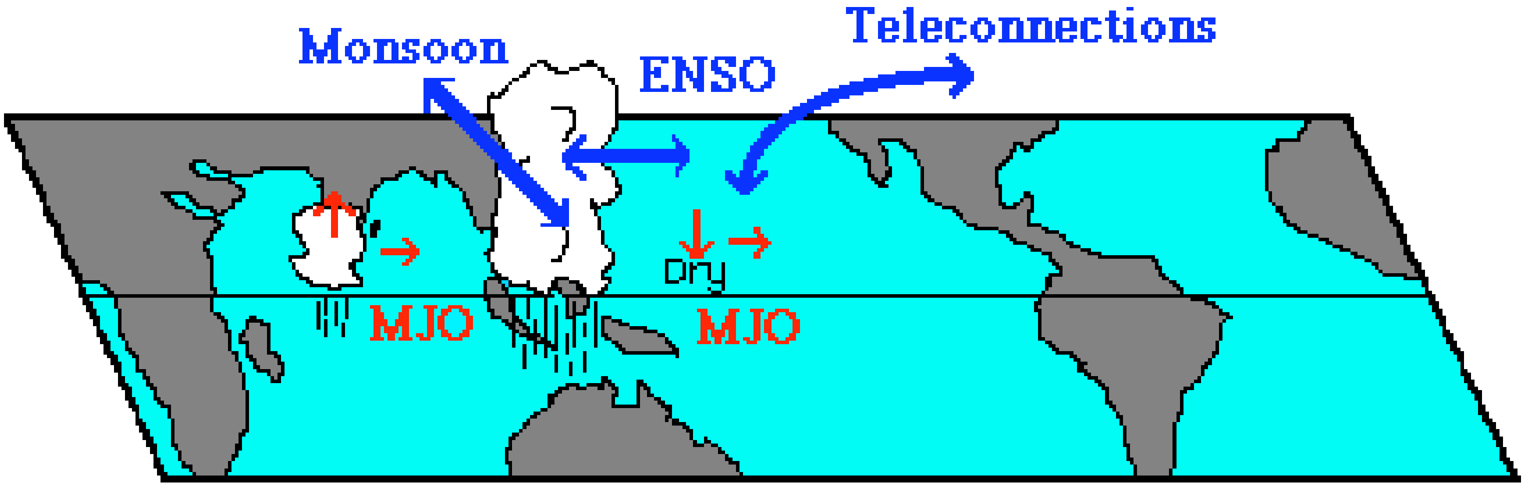
Courtesy of D. Waliser



MJO & Tropical Weather Variability



Courtesy of D. Waliser

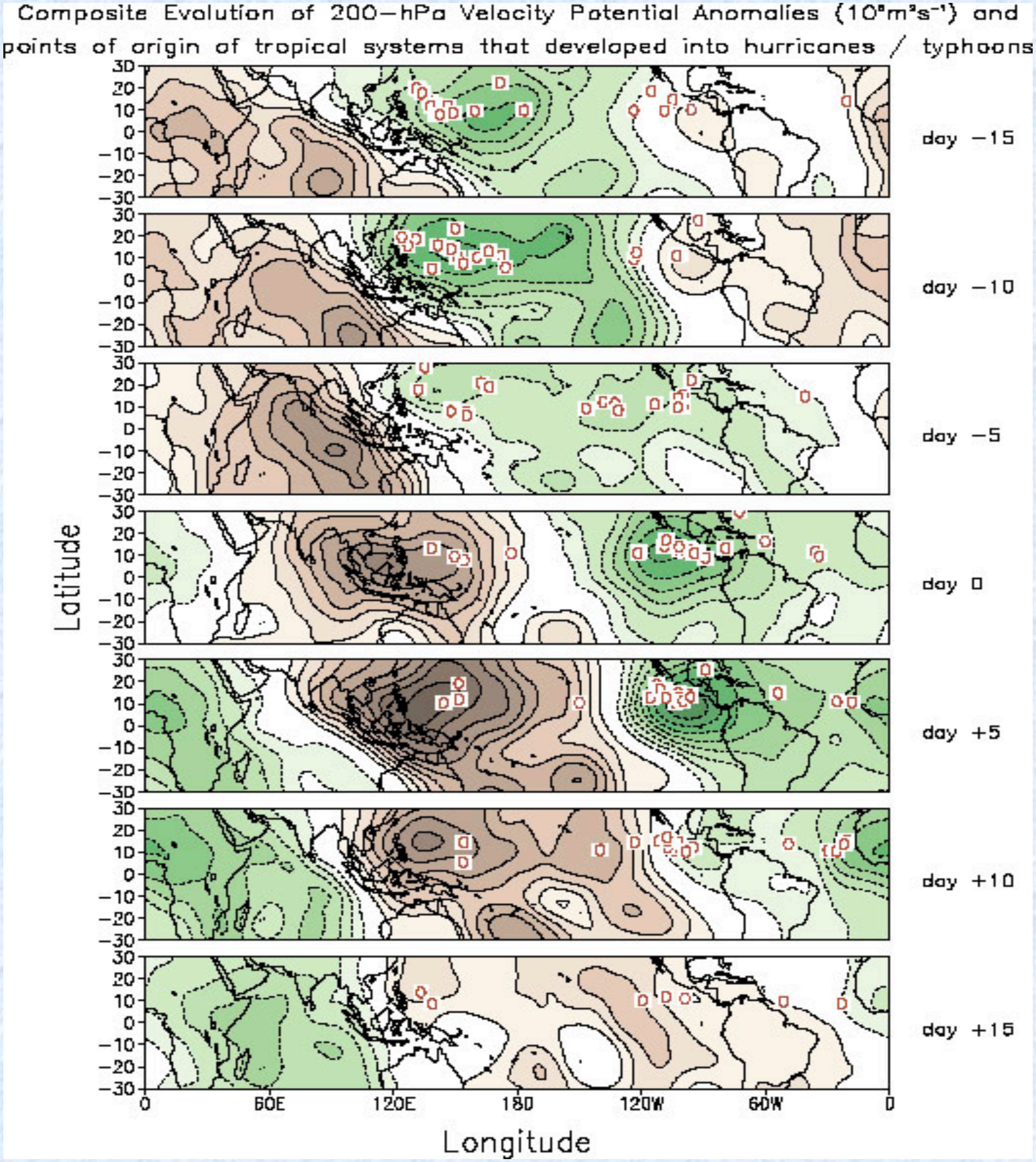


<Days –Weeks – Months – Seasons - Years>

- Diurnal Cycle
- Tropical Weather

  Low-frequency Weather Modulation
- Tropical Cyclones and Hurricanes

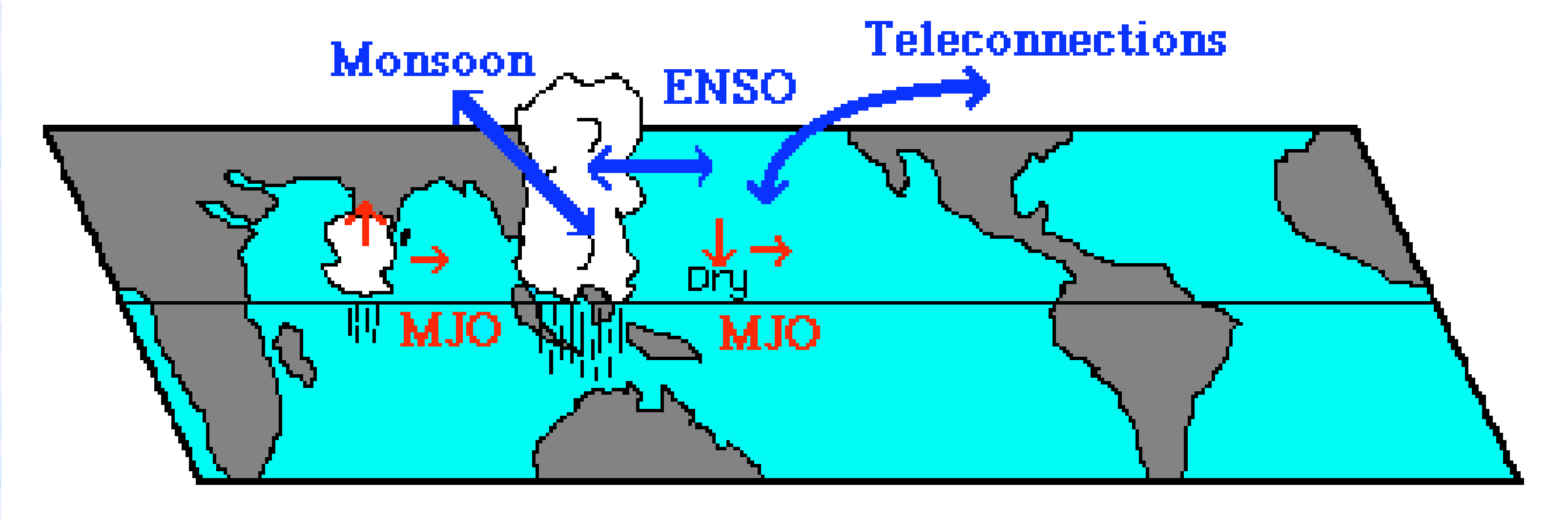
Courtesy of D. Waliser



MJO Influence on Tropical Storms/ Hurricanes

CPC/ NCEP/ NOAA

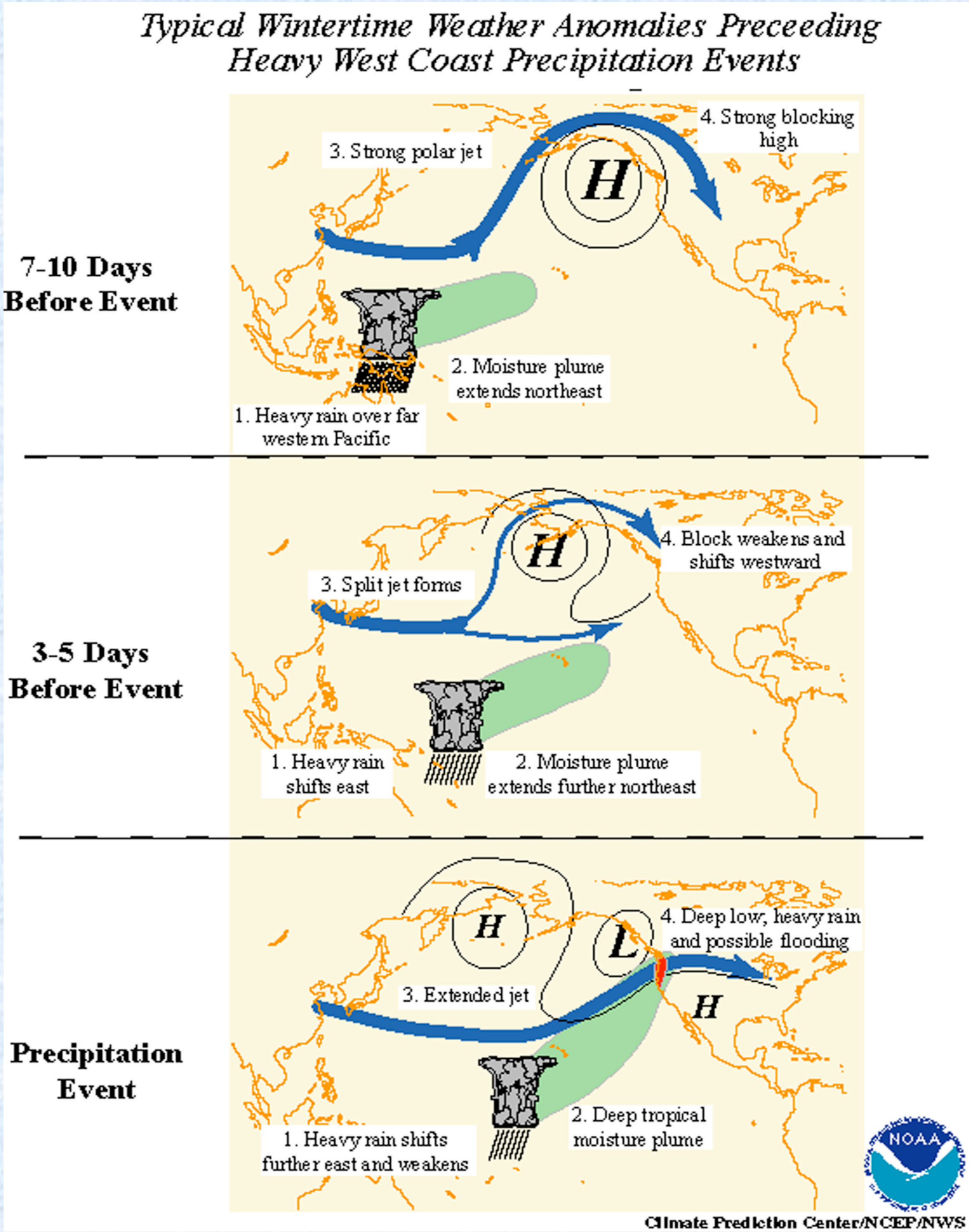
Higgins & Shi 2001



<Days –Weeks – Months – Seasons -Years->

- Diurnal Cycle
- Tropical Weather
  Low-frequency Weather Modulation
- Tropical Cyclones and Hurricanes
- Midlatitude Circulations

Courtesy of D. Waliser



MJO Influence on US West Coast Winter Rainfall

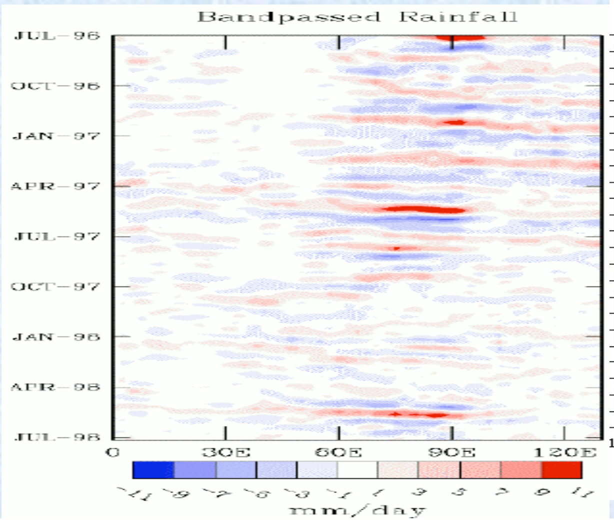
CPC/
NCEP/
NOAA

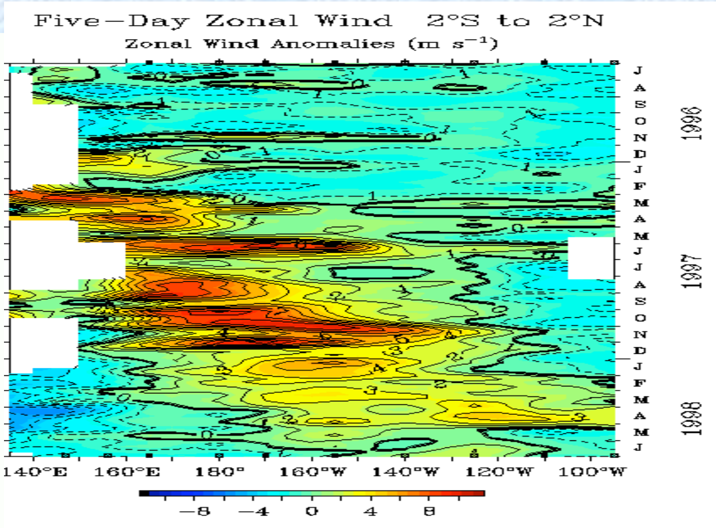
www.cpc.noaa.gov

Mo and Higgins 1998;
Higgins et al 2000;
Jones 2000

The MJO and ENSO

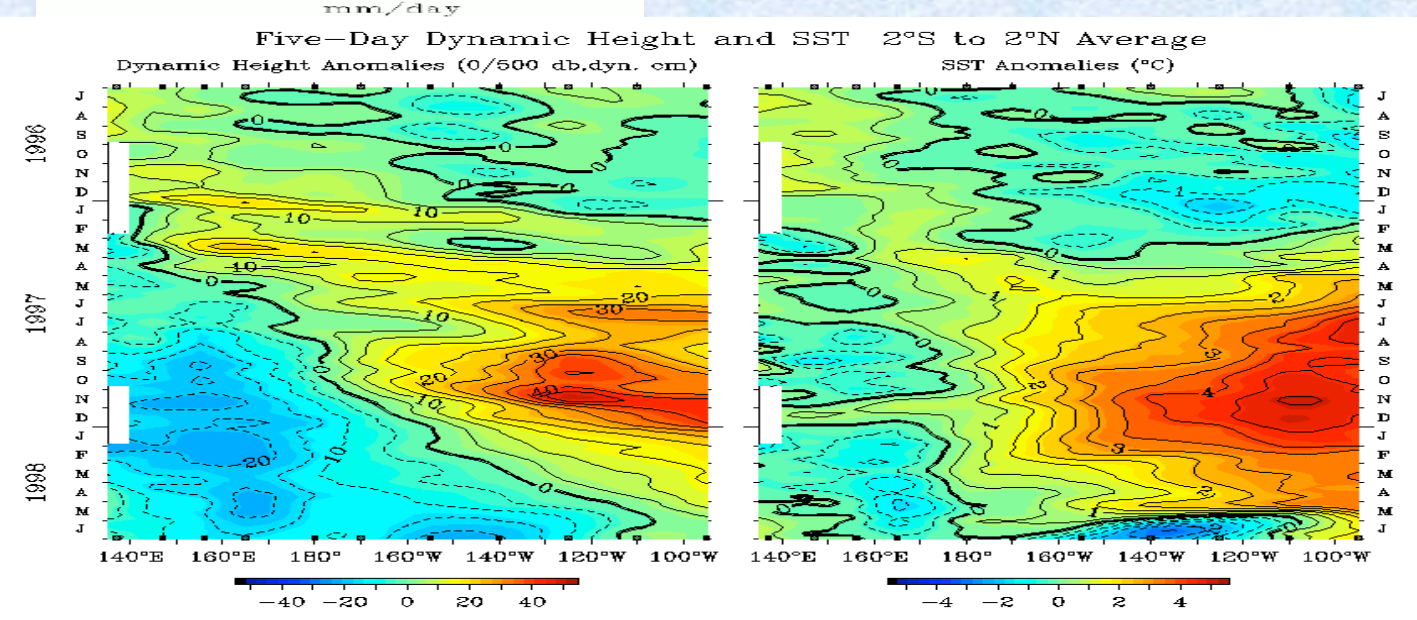
The Westerly Wind Burst Associated with the MJO may be an important trigger for El Nino





Courtesy of D. Waliser

1997/98 Event



Challenge
MJO
Modeling/Prediction/Theory

We are still facing great difficulties of accurately simulating and predicting the MJO using even the most sophisticated global climate and weather forecast models (Slingo 2005; Waliser 2005).

Furthermore, a comprehensive MJO theory that accounts for all the fundamental characteristics of the MJO has proven elusive (Wang 2005).

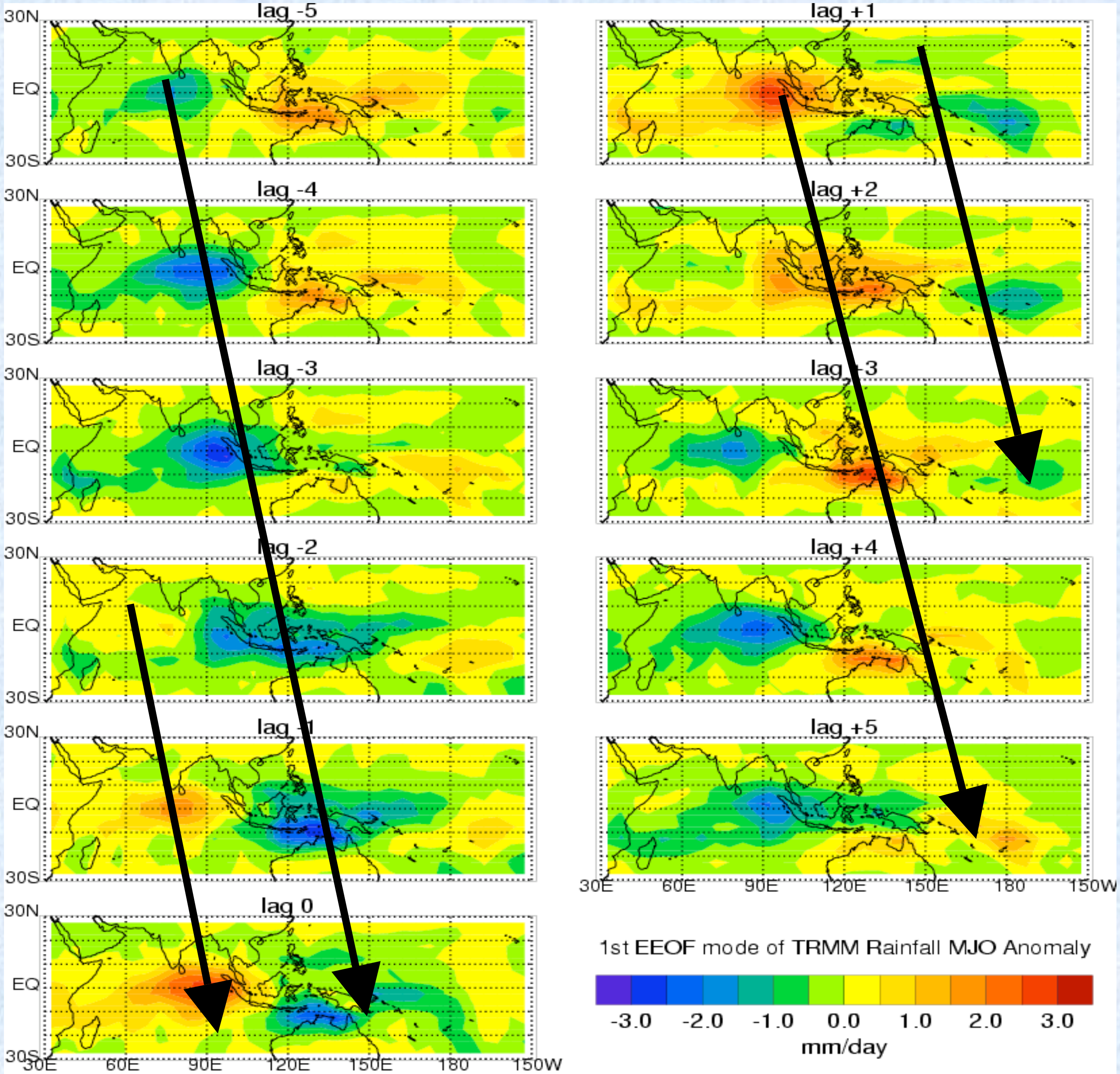
MJO Analysis

For each variable from TRMM, AIRS, and NCEP at each grid/level:

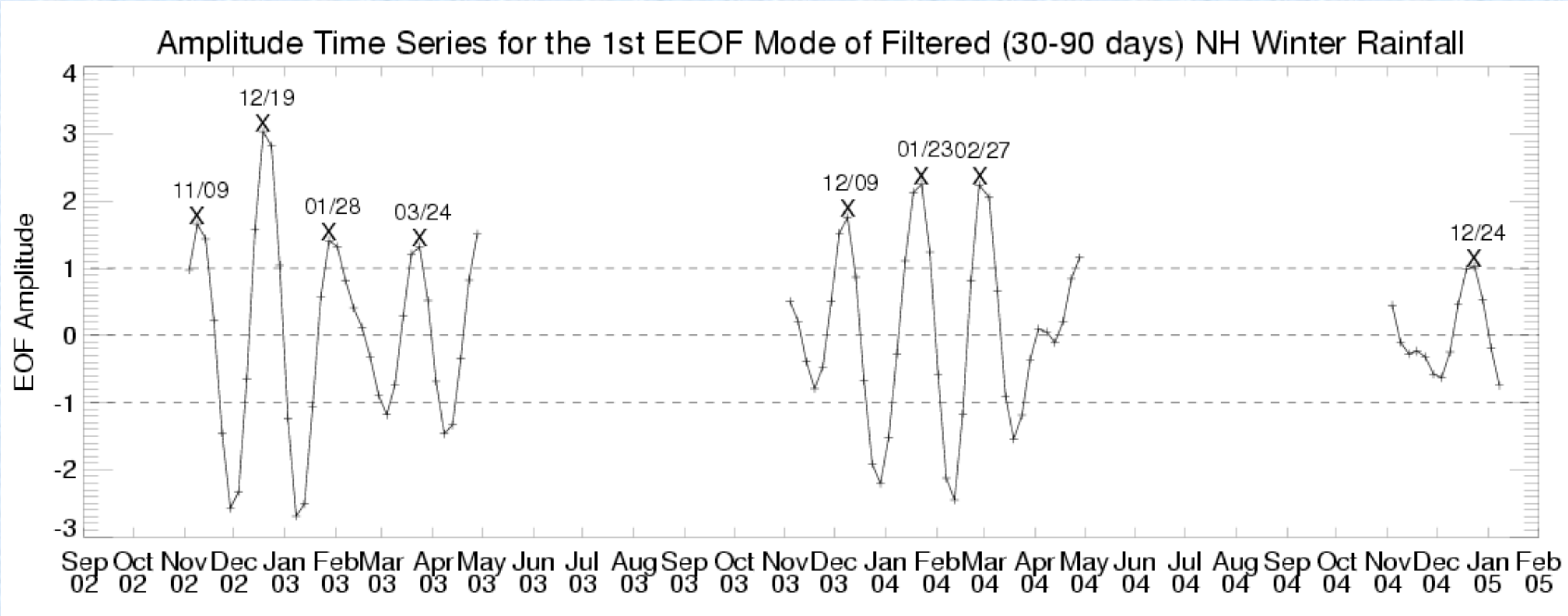
- **Bin the daily data into pentad data**
- **Calculate the 30-day running mean annual cycle.**
- **Calculate the pentad anomaly by removing the annual cycle.**
- **Retrieve the MJO anomaly using a 30-90-day filter.**

Compositing Procedure

(1) **Extended Empirical Orthogonal Function (EEOF) analysis (Weare and Nasstrom 1982) of TRMM rainfall MJO anomaly:**
Temporal Lag: 11 pentads (from –5 to +5 pentad);
Region: 30ºS-30ºN, 30ºE-150ºW (equatorial IO and WP);
Northern Hemisphere "Wintertime": November–April



Spatial–temporal pattern for the first EEOF mode of TRMM rainfall anomaly from NH wintertime (November–April) and the region 30ºN–30ºS and 30ºE–150ºW.



Amplitude pentad time series for the first EEOF mode of TRMM rainfall anomaly from NH wintertime (November–April) and the region 30ºN–30ºS and 30ºE–150ºW.

Compositing Procedure

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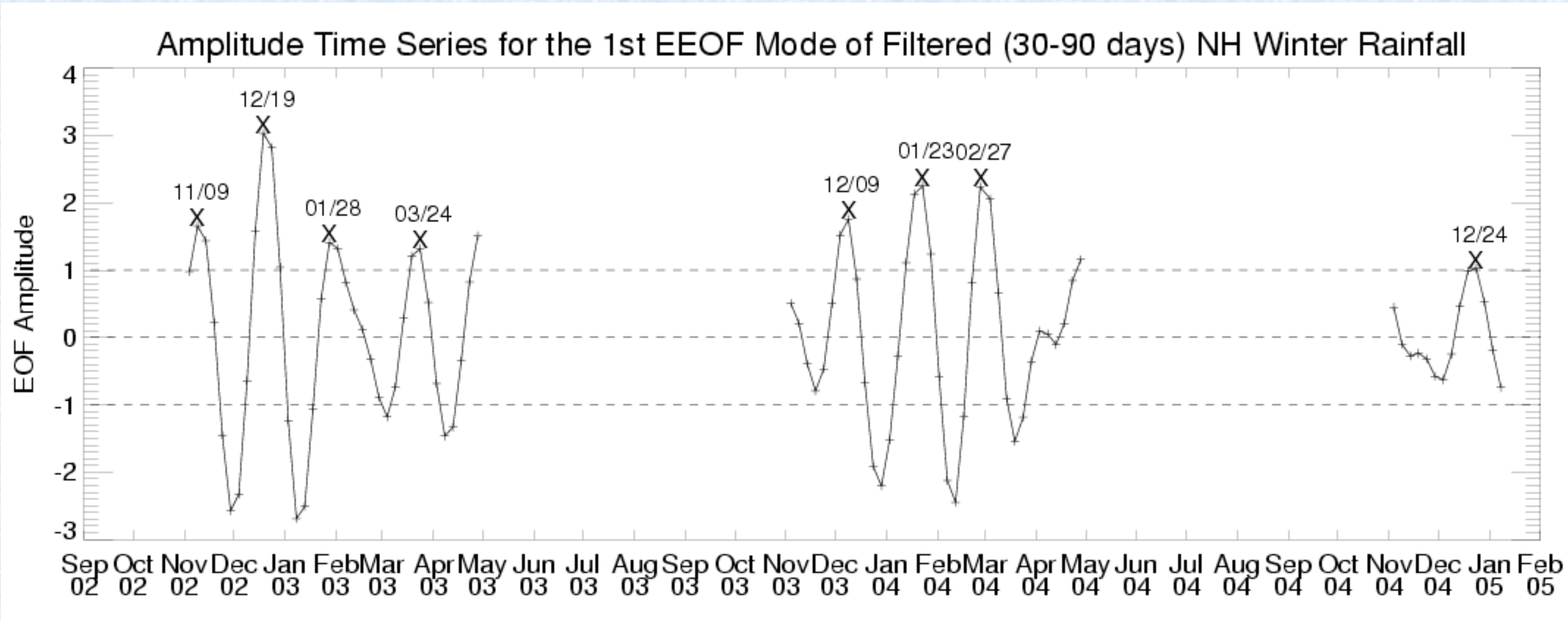
Temporal Lag: 11 pentads (from –5 to +5 pentad);
Region: 30ºS-30ºN, 30ºE-150ºW (equatorial IO and WP);
Northern Hemisphere "Wintertime": November–April

(2) **MJO Event Criterion: Peak time series amplitude > 1 STD**



Amplitude pentad time series for the first EEOF mode of TRMM rainfall anomaly from NH wintertime (November–April) and the region 30ºN–30ºS and 30ºE–150ºW.

Compositing Procedure

(1) Extended Empirical Orthogonal Function (EEOF) analysis (Weare and Nasstrom 1982) of TRMM rainfall MJO anomaly:
Temporal Lag: 11 pentads (from –5 to +5 pentad);
Region: 30ºS-30ºN, 30ºE-150ºW (equatorial IO and WP);
Northern Hemisphere "Wintertime": November–April

(2) MJO Event Criterion: Peak time series amplitude > 1 STD

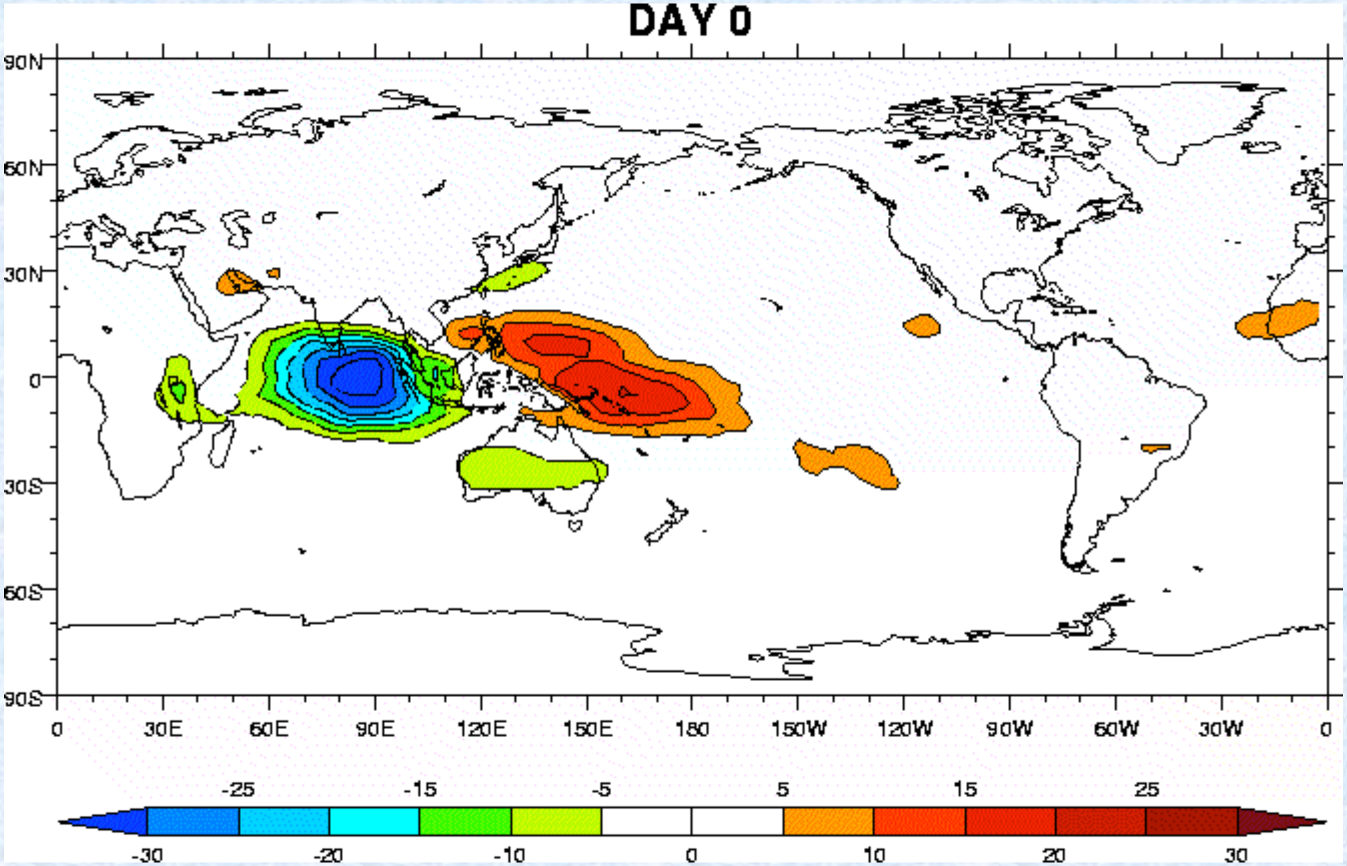
(3) For each selected MJO event, we consider the peak as lag 0 and then select 11-pentad (from –5 to +5 pentad) data of AIRS/NCEP T/q and TRMM rainfall.

(4) Average all the selected data to obtain a composite MJO cycle (11 pentads).

What's a MJO?

Some Fundamentals

A Typical MJO in N.H. Winter



OLR anomalies (W m-2); Blue = enhanced convection; Red = reduced convection

The images are spaced approximately 3 days apart and one whole cycle lasts approximately 48 days. From Matthews 2000.

Why is the MJO Important?

Interactions with Many Other Weather/Climate System Components at All Time Scales

Previous Observational Efforts

Observational analyses of the large-scale three-dimensional structure of the MJO have proven valuable in addressing this challenge.

Studies to date have mainly relied on the radiosonde data, the global reanalysis products, such as the NCEP/NCAR and ECMWF reanalyses, and in a few cases vertically resolving satellite data.

Limitations and Uncertainties

The spatial coverage of the radiosonde data is sparse in the equatorial Indian and Pacific oceans.

The reanalysis in these regions is mostly model-driven and may contain large errors from the model's boundary layer, deep convection, and cloud parameterizations.

The vertical resolution of previous satellite data, particularly in the lower troposphere, is rather low (~ 3-4 km) (Banzter and Wallace 1996; Myers and Waliser 2003).

Implications for MJO Theory

Observed MJO Vertical Structure from AIRS

MJO Vertical Thermodynamic Structure

MJO Vertical Moisture Structure